Developing an Integrated Method of Controlling the Flow of Departing Passengers: A study of passenger departure processes at Abu Dhabi International Airport

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Abstract

Today, airports form a key part of global infrastructure in an increasingly globalised world. There is great competition between them to attract passengers and serve airlines in their role of transporting people regionally and internationally. Abu Dhabi International Airport is one such airport. Terminal 3 is the home of Abu Dhabi's major carrier, Etihad Airways, one of the world's fastest-growing international airlines.

The research described in this thesis focuses on applying the Lean methodology to the passenger departure process in Terminal 3. The essential essence of 'Lean' is doing more with fewer resources by adopting a programme of continuous process improvement resulting in continually declining costs, mistakes and work-in-progress.

The special environment of any airport, especially a major international hub made applying Lean principles difficult. This resulted from the large presence of Class I wastes or *muda* which could potentially change, perhaps dramatically, at short notice. This made this research significantly different from previous applications of Lean philosophy. Also, large, cumulative variations in demand set in an environment where rapid expansion of the airport is taking place also created major difficulties because of the shifting flow of passengers. Despite this, the research succeeded in achieving its aim and developed various rules from parameters based on the acronym SERVICE and an associated implementation methodology based on the Lean philosophy. Together these will help airline managers and staff to eliminate the waste of available resources and so increase passenger flow through various stages of the process in line with Lean philosophy.

The research makes several important contributions to knowledge, especially in the field of Lean improvements. The contribution of this work arises from its systematic examination of the passenger departure process. The research has facilitated developing a detailed model which addresses both particular process groups and the effects of passenger class on the allocation and use of resources. This research has shown that large differences exist between the operating environment of a major international airport and those processes to which Lean principles have previously been applied. Nevertheless, despite these differences, this research has proved the Lean philosophy

may be usefully applied to airport operations. Operating conditions within the passenger departure process mean that understanding the special operating environment of airports is vital.

This research resulted in a discrete event simulation model of the airport much more accurate and detailed than those described in previous studies of passenger departure processes. The research then proved an improved model, which may be used experimentally to support conclusions reached from the broader application of Lean philosophy.

The research observed and analysed the effects of large and cumulative peaks and troughs in demand against a background of rapid development of Abu Dhabi Airport. The researcher also evaluated the special internal and external effects on the processes, often at short notice. Consequently, there is no single 'universal' solution because of the major need for operational flexibility and for a close correlation between operational and strategic need. Despite these many difficulties the results of this research are a practical and straightforward series of improvements, which may be applied by airport staff themselves without need for complex computer models, simulation or dedicated experts. This will create conditions for continuously improving process performance during the passenger departure process. It will also help managers accurately identify critical areas where more radical action of increasing physical resources is needed.

Finally, based on findings, the research makes several recommendations for further work.

Acknowledgements

Reaching the end of this journey made me recall each step I took to reach the last phase. It made me appreciate all of those who stood by my side, who guided me and those who supported me. It is time to show my sense of gratitude to them in this acknowledgement.

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Dedications

I would like to dedicate this work to my parents and family whose own sacrifices have made my Doctoral studies possible

I would like to thank my father for his endless encouragement and moral reinforcement to achieve my target, to my mother for her love, care and prayers, for my brothers and sisters for their extraordinary support. A special thank you for my wife, for handling being away from home, away from my two lovely daughters Shaikah and Shamma throughout their first years of life, I also thank her for her kind words to help me make it through.

Declaration

I declare that this research report is my own work and every effort has been made to indicate clearly the contributions from others by providing due reference to the literature, and acknowledgement. It has not been submitted before for any degree or examination in any other University. I further declare that I obtained the necessary authorisation and consent to carry out this research.

Publications

- Al-Dhaheri, A. and Kang, P. S. (2015) Using Lean Philosophy to Improve Passenger Departure Flow in Abu Dhabi Airport. *International Journal of Scientific & Engineering Research*, 6 (7), pp. 955 – 961
- Al-Dhaheri, A. and Kang, P. S. (2015) Lean Improvements to Passenger Departure Flow in Abu Dhabi Airport: Focus on Data from the Check-in Element .*International Journal of Advancements in Research & Technology*, 4(7) , pp. 122-134

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Confidential Appendix

NOTE : The sensitive nature of detailed data for airport operations, compelled the Abu Dhabi Airports Authority and Abu Dhabi State Security Services to make field-data collection the subject of a formal non-disclosure agreement to excludes specific references to numbers or patterns of passenger flow. Accordingly collected data is provided only in a series of access-limited tables in these Confidential Appendixes. Except for the Author's Supervisory team, those persons requesting access to confidential data, will be asked to make the request formally and in writing, giving reasons for their interest, and will be given access only after given formal permission by both the appropriate Research Ethics Committee of De Montfort University and the Chief Security Officer of Abu Dhabi Airports Authority.

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Abbreviations and Glossary

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ACI	Airports Council International
ADAC	Abu Dhabi Airports Company
ADIA	Abu Dhabi International Airport
API	Advance Passenger Information
AQT	Average Queuing-Time
ASQ	Airports Service Quality
ASQP	Airports Service Quality Performance
BQP	Batch and Queue Processing
CIBC	Standard Check-in Business-Class
CIBCS	Self-Check-in Business-Class
CIE	Standard Check-in Economy
CIEBD	Check-in Baggage Drop Economy
CIES	Self-Check-in Economy
CIFC	First-Class Standard Check-in
DES	Discrete Event Simulation
DoE	Design of Experiments
DOF	Degrees Of Freedom
EE	Emigration Economy
EFB	Emigration First/Business-Class
GCC	Gulf Cooperation Council
GPSS	General Purpose Simulation System
IATA	International Transport Association
ICAO	International Civil Aviation Organization
ICT	Information and Communications Technology

MDPs	Markov Decision Processes
MQS	Maximum Queue Size
PDA	Personal Digital Assistant
SE	Security Economy
SFB	Security First/Business-Class
SLAM	Simultaneous localization and mapping
STP	Security Transfer Passengers
T3	Terminal 3
TP	Throughput
VSM	Value Stream Mapping
WIP	Work-In-Progress
%Wa	% [of processing station] Waiting Time
%Wo	% [of processing station] Working Time

Chapter 1 : Introduction

1.1 Introduction

Today, airports form a key part of global infrastructure in an increasingly globalised world. There is considerable competition between them to attract passengers and serve airlines in their role of transporting people regionally and internationally. Nowhere is this truer than in the Arabian Gulf. Here, not only is regional passenger traffic growing significantly, but six airlines located in the Gulf have truly global ambitions and wish their own airport to become a major hub in the global network. Abu Dhabi International Airport (ADIA) is one such airport (Adia 2013).

The various authorities, who operate international airports, are constantly striving to improve their operations and service to passengers. In this they are not alone. Other industries and sectors have also continuously faced the same problems. In the 1980s manufacturing industry sought global competitiveness and found itself needing world-changing transformations (Womack, et al. 1990). The answer then was the adoption of Lean philosophies and methods (Ohno 1988, Womack, et al. 1990). These profoundly changed the way manufacturing was conducted and involved new ways of making things and coping with global over-capacity. Now airports find themselves having to face similar issues and potentially 'Lean' can provide solutions just as it did for both manufacturing and service sectors.

This thesis describes a project applying Lean thinking to the passenger departure process by examining and analysing in detail the process at each passenger processing station. The project will additionally use Discrete Event Simulation to investigate various improvement scenarios, in a way neither possible nor allowable with real-time operations of a major international airport. This thesis proposes solutions based on Lean philosophy and improvement measures, each of which will have a demonstrably beneficial effect on different stages of the process and on the entire departure passenger process.

Terminal 3 is the home of Abu Dhabi's major carrier, Etihad Airways, one of the world's fastest-growing international airlines and so offered scope to research the departure process connected with various aircraft, including the world's largest passenger aircraft. The research focussed on only one airline, Etihad, for which Terminal 3 is exclusively dedicated.

There are three major elements to this project; a thorough field investigation of the operations of Terminal 3 of ADIA, a simulation of the Terminal's existing operations and of various potential Lean improvements to the passenger departure process and the use of tools and techniques developed in manufacturing and service industries and not normally found in airport operations.

1.2 Background to the Research

The essential essence of 'Lean' is doing more with fewer resources (Womack, et al. 1990). Lean achieves this by adopting a programme of continuous improvement resulting in continually declining costs, mistakes and work-in-progress. Lean reduces different types of waste (Section 2.5.1) and uses a different approach to planning and control (Slack, *et al.* 2010). Here, 'waste' means any operation that neither adds value for the customer nor is an essential component of the process (Khalil, et al. 2010). Much of this is achieved by Lean problem-solving i.e. identifying the root cause, and then permanently dealing with the problem at source, rather than repeatedly solving the same problem.

As the service environment grows in importance in advanced economies increasingly, researchers like Bicheno(2008), Piercy and Rich (2009) and Beuster(2011) have shown that Lean principles can be similarly applied in the service sector to achieve not only reductions in waste, but major improvements in customer service.

1.3 Abu Dhabi International Airport

Abu Dhabi is one of the seven Emirates within the State of the United Arab Emirates (UAE) and is the administrative capital of the State. ADIA, first located to the site in 1982, is now one of the fastest-growing airports in the world. Since it was first developed, ADIA has undergone several important periods of development. During the time when this research was conducted, the airport is undergoing further development in major expansion programme. Despite this, ADIA is the smaller of UAE's two main international airports, with the second and larger one at Dubai where a rival airline, Emirates Airways is headquartered and which acts as a hub for many other carriers. (Adac 2013).

In its current state of readiness in 2013, ADIA already has a handling capacity of around 12.5 million passengers annually. When the full expansion currently taking place is complete, the airport will have a capacity of 47 million passengers annually, many of whom are transit passengers. Serving their needs effectively and efficiently while staying sensitive to the needs of passengers is a major strategic aim in this development.

The airport serves more than forty international airlines delivering passengers to ninety-three destinations in 54 different countries. The airport has already won several major awards for service quality (ADAC 2013). As a result, quality of operations and passenger satisfaction are significant criteria for any improvement of ADIA airport operations.

1.4 Research Aim and Objectives

The main aim of this research is to develop a single methodology to reduce the waiting time at processing stations and improve quality of service (QoS) so that passengers spend more time in duty free at the departing passengers at Abu Dhabi international airport. A single methodology means that the proposed approach is applicable (without any changes) to each element (i.e. group of processing station, such as check-in, immigration, etc.) of the passenger departure process (PDP).

Research objectives

1. Develop process mappings to understand the logical process flow and identify the factors causing the variability.
2. Design experiments using the factors influencing the waiting time and QoS for PDP flow and develop discrete event simulation (DES) model from the process mappings to identify mixed levels of variability in order to address the airport operational problems affecting the PDP, which influence the applicability of Lean principles about the efficient flow of passengers.
3. Analyse the simulation results based on default settings to identify cause and effect influencing the passenger waiting times and QoS.
4. Develop the rules to improve the PDP flow based on the identified root cause/s.

5. Apply rule-based approach to the PDP flow to improve waiting time regardless of the changing condition during complex combination of passenger flow at various times.

1.5 Research Problems

1.5.1 The Airport Environment

The research took place in an airport environment which is fundamentally different from the manufacturing setting in which Lean theory and principles first developed.

The first major difference was the service environment itself. Researchers have recognised for some years that a service environment calls for a quite different Lean approach (Bicheno 2008, Piercy and Rich 2009, Womack and Jones 1996). A major reason to avoid the terminology “industrialisation of service” (Bowen and Youngdahl 1998) is because certainly, it would be unacceptable to passengers, airlines and airport operators (Correia, *et al.* 2008, Jin-Woo, *et al.* 2006, Mei Ling, *et al.* 2010).

However as Section 1.5.2 shows, the airport environment is also significantly different to most other service environments.

1.5.2 Issues Special to Airports

a. Process or System: Because the special disjointed nature of individual processes during departure which are deliberately separated from one another for economic and occupational reasons, passenger departure could be described either as ‘a process’ (Slack, *et al.* 2010) or as a ‘hard system’ (Checkland 1981) which has external inputs and outputs, a boundary and subsystems. Understanding that ‘departure’ is also a system allows additional scientific rigour to be brought to the problem which helps further improve any results found (Jackson 2003). The airport departure process is described in more detail (Section 2.8)
b. Several Different Parties: Each processing station and elements of the passenger departure process are operated by a different entity which each uses its own personnel and information systems (Bittel, *et al.* 2007, Graham 2007).

c. Passenger Involvement: Unusually, even for Lean service operations, passengers as both customers and 'components' are directly involved in every operation and at every stage of the departure process (Bittel, *et al.* 2007).
d. Economic Factors: as part of the economic model adopted by all airport operators, delays have been deliberately built into the process, especially in passenger waiting areas, where various concessionary activities form a significant part of the airport's income (Freathy and O'connell 1999, Vojvodić 2008, Volkova 2003).
e. Legal Factors: every stage of airport operations are closely governed by national and international laws, especially those which are vulnerable to security risks and terrorism (Bittel, *et al.* 2007, Kaffa-Jackou, *et al.* 2009). Laws and regulations may change suddenly and quickly as new threats emerge. The legal framework means this research is not free to choose solutions on the basis of Lean theory alone.
f. Uncertainty of Output Time: unlike any other type of Lean operation, the time of output (aircraft embarkation) is often not under the direct control of any of the parties involved, but may be governed by external factors such as weather, aircraft breakdown, international air traffic factors etc. (Cheng-Lung and Caves 2004, Graham 2007). Even so, in most cases, the time of check-in, the first stage of the departure process is normally fixed against scheduled departure time.

Taken together, these factors create a challenging environment for developing Lean systems and the solutions put forward in this thesis provide a major contribution to knowledge in the field.

1.5.3 The Nature of the Departure Process and Its Components

The departure process is not a single process but rather a series of loosely-linked processes. These loose linkages are quite deliberate and have been put in place as buffers to allow variations beyond the control of the airport. These buffers also form a significant part of any airport's income from concessionary activity as they allow passengers time to purchase various commercial services or to buy goods (Freathy 2004, Freathy and O'connell 1999, Vojvodić 2008, Volkova 2003). This means that the objectives is not necessarily to reduce the full passenger departure process time as would normally be the case, but rather to improve individual processing stations and thereby release passengers to perform more enjoyable functions within the airport enabled by greater free time between processes.

1.5.4 Increasing Operations in Terminal 3

ADIA is rapidly increasing its operational capacity and as Section 1.3 described, will almost quadruple the number of departing passengers in the near future. This means that the research had to actively consider the effects of such a large increase in operations when proposing solutions. As an example, the number of passengers processed in January 2014 increased 14.5% over those travelling in January 2013 (Adac 2013).

1.5.5 Standard Departure and Transfer

Various factors mean that there is not a single route through the departure process. These include:

- Treatment of different classes of passengers,
- Adoption of various technologies which allow passengers to follow either a traditional human-interactive check-in process, or to use terminals or remote check-in systems,
- Treatment of different passengers.

Instead there are several parallel interlinked processes or routes passengers may elect to take. Additionally, as a major international hub, there is a large volume of transfer passengers who come through only part of the departure process. Transfer passengers, whose numbers vary widely from one flight to another, form a significant proportion of ADIA's departing passengers. On some aircraft it is as high as 100% and on others and low as 0%.

1.5.6 The Difficulty of Application of Lean Principles to Airport Operations

The various issues highlighted in section 1.5.1 and 1.5.2 add significantly to the difficulty of applying Lean principles to airport operations because of differences between it, classical Lean environments and Lean service environments. In this respect, some application of systems theory also helped refine solutions.

Service quality remains an overriding consideration for most passengers and they will simply not tolerate being treated as components of an industrial line. More sensitive approaches have been needed to satisfy the needs of passengers, many of whom are highly demanding; the strategic aims of ADAC, and various bodies such as Skytrax and the Airports Council International (ACI). In the last case, ACI apply the Airport Service Quality initiative to objectively judge relative service quality standards in airports worldwide, including in the departure process. They use a range of management tools to assist airports to improve customer service, benchmark passenger satisfaction and measure actual service levels delivered. These may not entirely coincide with Lean principles, though they often do (Aci 2014).

Normally a single body closely controls unit flow through the process continuously from beginning to end. For various reasons described earlier, this is not possible because of the loose coupling of individual processes in airports, different loci of control and external factors. The resultant loose linkages mean that passengers rather than various airport operating authorities have much greater degree of control where they are physically located in the process at any given moment than would normally be the case for industrial components.

Additionally, because of external events, two concurrent timescales operating in the airport; one based on scheduled departure time and the other based on actual departure time. Empirical results in all airports including in the current study, show these are only rarely the same. The use of two timescales of this type is another unusual factor when considering Lean systems.

1.6 Structure of the Thesis

The thesis is composed of nine chapters as follows:

Chapter 1: Introduction this chapter presents research background, research aim and objectives and research problems

Chapter 2: Lean Principles and Airport Operations; a literature review of Lean principles including fundamental Lean concepts and the seven types of waste. The Chapter includes a review of other work carried out by researchers within airports worldwide and definitions and descriptions of passenger flow during departure.

Chapter 3: Airport Modelling; examines problem-solving in Lean and passenger departure flow as well as existing models, problem-solving tools and improvement cycles developed by other researchers and theorists.

Chapter 4: The research methodology; a description of the research methodology used which includes a detailed description of research questions and objectives and enumerates the research philosophy, research approach and research strategies employed in this research. It also provides a detailed explanation of why certain data types were collected.

Chapter 5: Data Collection-Field Study Data;
This chapter presents and discusses data collection methods adopted in this research. It provides justification for each method adopted

Chapter 6: Presentation of Results; this chapter presents the data collection of the research.

Chapter 7 Developing the Rule-Based Departure Process; The chapter presents and discusses the rules implementation, development, and how the rules linked, applied and used to derive the improvement.

Chapter 8 Development of Knowledge Base to Improve the Process of Passenger Flow;
This Chapter discusses the results of the research and gives proposals for the improvement of the departure process using Lean principles. The Chapter also present the main limitations of the research.

Chapter 9: Conclusions and Recommendations; this chapter presents the research conclusions, contribution to knowledge which this research has achieved and provides recommendation for further.

Chapter 2 : Lean Principles and Airport Operations:

2.1 Overview

The purpose of this Chapter is to define certain fundamental terms and to present the Lean principles which will be applied to passenger flow in the airport departure process. The aim is to achieve synchronised processes which avoid passengers spending excessive time in queues in front of processing stations. In this way, they can move smoothly and continuously from one station to the next until final departure.

2.2 Basic Definitions of Process Flow

This section introduces the process flow definitions, which will be used throughout the thesis to exemplify the airport departure process flow and proposed methodology.

Davenport (1993) defines a [business] **process** as:

> *"a structured, measured set of activities designed to produce a specific output for a particular customer or market.."(1993, p.2)*

In contrast to product focused environment, the main focus is how work is done instead of what, which means the activities are orders across time and space with defined inputs, outputs, beginning and end. According to Davenport (1993), "*Taking a process approach implies adopting the customer's point of view. Processes are the structure by which an organization does what is necessary to produce value for its customers*". The main focus of this research is on the airport departure process flow improvement.

Khalil (2005: p.24) defined ***flow*** in manufacturing process as "*the movement of materials through the sequence of processes required to convert raw materials to finished components*".

A widely accepted definition of ***passenger flow*** is given by the US Bureau of Transportation Statistics (Gray 1989: p.46)as "*The number of passengers who pass a given location in a specified direction during a given period*".

For the purpose of this research recognising that some check-in operations may be performed outside the airport, therefore, research here has defined the physical ***passenger departure flow*** as:

> *"The flow of passengers starts immediately on entry into the departure terminal and terminates immediately before boarding the aircraft".*

Transit passengers are those who arrive at the airport by air, and transfer to another aircraft through part or all of departure facilities. The extent of use of facilities depends on the types of transfer, how the airport is configured and particular airline services used (De Barros, et al. 2007).

2.3 Airport Terminal

To place the research contextually, in respect of the airport terminal, Jim and Chang (1998) observe:

- Any airport serves as an interface between ground and air transportation.
- The airport may also serve as an interface between passengers arriving and departing by air (transfer passengers).
- The passenger terminal is the part of the airport involved with flows of passengers and baggage.
- Passengers moving through the airport terminal are often subjected to delays, queues and bottlenecks. These are usually due to the constraints of the capacity of service facilities.

Abu Dhabi International Airport is viewed not only as a significant national asset, but as an enterprise which like other airports worldwide are expected to be managed with a high degree of efficiency while providing high levels of public service (Vasigh and Gorjidooz 2006) and a range of other operations directly or indirectly linked to flying such as security. Airports like Abu Dhabi are expected to lower operating expenses and at the same time accommodate ever-increasing demand both from its national carrier Etihad, and from other carriers which use the airport either as a destination or a hub.

Airport passenger departure systems consist of a number of processing stations where 'potential passengers' are transformed into 'approved departing ('originating') passengers' through a series of workstations. These include ticket and baggage deposit counters, ticket screening, security screening, and departure lounge and boarding control (Correia, et al. 2008). Each processing station is normally joined to others by a system of circulation areas which may include corridors, lifts, escalators and moving walkways, or in the case of special-needs and disabled passengers by motorised transportation. Each airport also has a number of waiting and concessionary areas, where passengers are provided with amenities such shopping facilities, restaurants and cafes, unrestricted passenger waiting areas, prayer rooms, and communication facilities (Correia, et al. 2008). These help passengers pass the time when not being processed during the period between scheduled check-in time and scheduled departure and provide activities to relieve the wait when external factors cause further delays to flight departures.

Thus the passenger departure system is unlike a manufacturing or normal service environment and consists of a series of subsystems or process workstations where passengers are controlled, surrounded by areas where control is relaxed and passenger activities are largely dictated by the individual. Section 2.6 of this Chapter examines this in more detail.

2.4 Lean Principles.

Lean principles grew from the development of the Toyota Production System used when manufacturing automobiles, and later described in a 1990 seminal work by Womack, Jones and Roos(1990). Although 'Lean' was firmly rooted in the automotive manufacturing the sector did much to establish Lean as a wider operational concept. In common with other competitive international businesses, various attempts have been made to improve airport efficiency and one that has so far been little used is the application of Lean principles to airport operations. One important innovation, which Lean principles introduced, was the concept of flow synchronisation. Lean aims to deliver service exactly when required with perfect quality and no waste (Slack, *et al.* 2010).

While Lean techniques first started in the manufacturing sector (Womack and Jones 1996, Womack, et al. 2007), Lean principles have been used in various industries and settings since, including the service sector. Bowen and Youngdahl (1998) noted how successfully Lean principles have been used in applications as diverse as fast food restaurants, banks, airlines and hospitals as they reacted to the same commercial and service imperatives as first appeared in manufacturing. They note resistance to service companies using Lean techniques was the potential for their leading to 'the industrialisation of service'.

Nevertheless, the special nature of airport environment poses particular challenges compared to both manufacturing and other service operations and these will be further evaluated later in this thesis. Authors including (Chawdhry 2009, Jim and Chang 1998, Rauch and Kljajić 2006, Roanes-Lozano, et al. 2004, Van Dijk and Van Der Sluis 2006) and many others have previously contributed the wide range of variables which are applicable to the airport departure process as described in Section 3.5.

This research will focus on flow synchronisation (Slack, *et al.* 2010) and reducing the effect of variability (Khalil and Stockton 2003, 2004). These create the foundations of Lean processes and link the passenger flow described in paragraph 2.4.1 with Lean's Five Fundamental Concepts.

2.4.1 Lean's Five Fundamental Concepts

In a further development of Lean, Womack and Jones (1996) identified five key principles which were expanded by Emiliani (1998) as follows (Table 2-1):

Table 2-1 Lean Principles
Derived from Emiliani (1998)

Lean Principle	Description	Application to Airport Processes
1. Identify Customers and Specify Value	Only the customer (the passenger) can really define the value of a product or service. All non-value activities may be targeted for removal as 'waste' or muda	This is achieved by meeting the passenger's needs quick, problem-free delivery at each processing station and in the total departure process, rather than specifying value from the airport operators' perspectives. The focus will be on removing those activities that consume time and resources but create no value for the passenger
2. Identify and Map the Value Stream	The value stream is "the specific activities required designing, order and providing a specified product [or service]" (Womack and Jones 1996: p.311). Identifying the value in Lean systems means understanding all activities needed to produce a specific service outcome	Identifying value means understanding all activities needed for a specific outcome at each processing station, followed by optimising the whole process as seen from the passenger's perspective

Lean Principle (cont'd)	Description	Application to Airport Processes
3. Create Flow by Eliminating Waste	Flow' is "the progressive achievement of tasks along the value stream" (Womack and Jones 1996: p.306) and identifying activities needed to process those parts of the service without interruption. Contrasts with traditional systems which build up large batches of 'inventory' for continuous processed for a period - batch and queue processing (BQP). Typically in most service operations, less than half the activities add value to the customer. (Emiliani 1998)	Batches of inventory equate to passenger queues. In contrast, a proper flow system responds to the value specified by end-users and passengers.
4. Respond to Customer Pull	The concept of 'pull' in Lean processes means the customer creates demand which activates the system. Contrast to BQP which are designed to meet the service operators' own needs driven by demand forecasts and in doing so, create waste within the system. Lean producers should only deliver the product or service the customer wants, when they want it	Push is created by the departure-window determined in advance. In airport processes, the major difficulty is that it is actual departure time of the aircraft which creates the pull in the system, rather than straightforward customer demand.
5. Pursue Perfection	When an organization does the first four steps well, all activities become transparent	By encouraging transparency, various airport operators can more easily identify and eliminate waste and focus on improving activities which create value.

2.5 Wastes

'Waste' is defined as "any activity that does not add value". Slack, et al. (2010: p.435) argue that reducing waste is the most significant part of Lean philosophy as often only 5% of the time is spent adding customer value. The remainder is wasted and this forms the basis for Lean system improvements.

The first step to eliminate waste is to identify it. Lean philosophy describes the seven types of waste within most processes (Hines and Rich 1997).

2.5.1 The Seven Types of Waste

There are seven commonly accepted wastes in Lean production systems first developed by Taiichi Ohno (1988) in Toyota, numbered 1-7 in Table 2-2 .

Table 2-2 The Classic Seven Lean Wastes
Derived from Ohno (1988)

Waste	Description	Application to Airport Processes
1. Overproduction	Producing more services than are required at any particular time.	This does not apply to the passenger departure process as only passengers with valid tickets and documents can legally be processed. Arguably, however processing capacity in the form of the excessive provision of manned workstations constitutes overproduction.
2. Waiting	Producing queues in a bottleneck.	This occurs at every processing station and in intermediate waiting areas and facilities such as queue check-in process etc.
3. Transport	Unnecessary distance travelled between processing stations during work-in-progress.	Although minor modifications are possible, this is largely dictated by the physical layout of the airport, and the need to cater for many different flights and aircraft sizes.
4. Inappropriate Processing	Carrying out operations which are wasteful or unnecessary or caused by defects, overproduction or excess inventory.	Except in exceptional circumstances this does not occur because of the legal requirements about processing passengers and the use of specific documents with the process.
5. Unnecessary Inventory	Maintenance of excessive amounts of raw materials or work-in-progress.	This does not apply to the passenger departure process as only passengers with valid tickets and documents can legally be processed. In any event, it is in airport operators' economic interests to generate excess inventory of passengers within intermediate passenger waiting areas.

Waste (cont'd)	Description	Application to Airport Processes
6. Unnecessary Motion	Additional steps taken by employees and equipment to offset the effects of an inefficient process layout or any other cause due to 1-5 above.	Although minor modifications are possible, this is largely dictated by the physical layout of the airport, and the need to cater for many different flights and aircraft sizes.
7. Defects	Products or services which do not conform to the specification or to passenger expectations.	This does not apply to the passenger departure process as because passengers must be dealt with in a legally prescribed way.

These represent the 'classic' seven wastes or *muda* which are applicable to operation process. Womack and Jones (1996) use the term *muda* to define waste is being any human activity which absorbs resources and creates no value. Nevertheless, Table 2-2 illustrates some of the difficulties applying Lean to airport operations.

As well as the seven classic wastes above, others have since been developed. The most important of these are 'the design of appropriate goods and services' (Womack and Jones 1996), wastes caused by 'untapped human potential' (Abdi, et al. 2006) and 'failure demand' (Seddon and O'donovan 2010). These are shown in Table 2-3.

Womack and Jones (1996) recognised the need to apply Lean specifically to services, suggesting that it is imperative to identify what the end-customer or user actually wants, defining it by meeting the customer's needs affordably and at a specific time. This becomes a critical starting point for Lean thinking. Abdi *et al*(2006), describes that meeting customer needs and expectations are a "core aspect" of service marketing where the customer is closely involved with production of the service. The importance of service quality within the passenger departure process has been commented on by several authors including (Jin-Woo, et al. 2006, Mei Ling, et al. 2010). Service quality conditions significantly affect an airport's competitiveness against other airports and airlines which use them. These directly affect as drivers of passenger satisfaction, an airline's image and passengers' future behavioural intentions (Jin-Woo, et al. 2006). Each of these is important in the wider Gulf where several airlines compete aggressively for international business and their position as the most important regional hub. Issues such as external access and facilities used as buffers such as restaurants and duty-free shopping are also an important consideration for passengers in their choice of airport and airline (Mei Ling, et al. 2010).

From this perspective, the Lean approach helps to define, refine and improve the entire value chain (Lovelock and Wright 2001) in the airport departure system.

The concept of the value stream described in Table 2-1 is fundamental to understanding Lean services provision particular. There are three types of activities in the value stream, two of which are *muda*and only one adds value. These are defined as:

- "Value-added: those activities that unambiguously create value.
- Type I Muda: activities that create no value but seemed to be unavoidable such as regulatory requirements, current technologies and existing assets
- Type II Muda: activities that create no value and are immediately avoidable. Womack and Jones (1996)

Thus the Lean principle of flow is the

> *"….. progressive achievement of tasks along value stream so that a [service] proceeds from design to launch, order to delivery ….. Into the hands of the customer with no stoppages, scrap or back flows"* (Womack and Jones, 1996: p.306)

Table 2-3 Three Additional Lean Wastes

ADDITIONAL WASTES		
Waste	**Description**	**Application to Airport Processes**
8. Design of Goods and Services (Womack and Jones 1996)	Inappropriate services which do not meet service specifications or customers' needs.	This does not apply to the passenger departure process as because passengers must be dealt with in a legally prescribed way. However, peripheral services, including those used in general buffers where passengers will wait between processing stations are important both to passengers and the Airport Authority.

Waste (cont'd)	**Description**	**Application to Airport Processes**
9. Untapped Human Potential (Abdi *et al* 2006)	Unused potential in service employees.	The potential of individual service employees may be better used though the overriding difficulty in the departure process is that employers differ from one station to the next and so cross-use between stations may be restricted. However, provided peak times for arrival and departure processes differs significantly, therefore, some cross-use of employees may be possible.
10. Failure Demand (Seddon and O'Donovan 2010)	"*Demand caused by a failure to do something or do something right for the customer*" This includes not solving problems, issuing documents customers have difficulties with, and so on.	The legal nature of many departure processes means that documents and services must follow a prescribed format. The trend has also been for standardising or 'industrialising' service. While it essential in manufacturing, standardisation actually limits and service organizations' ability to absorb variety and deal with variation. However, reliable computer systems and the availability of various facilities, including for example baggage trolleys may have important effects.

Under Lean, using buffers to isolate workstations allows problems to go unresolved, even serious ones (Slack *et al* 2010). A further complexity is that, from the passenger's perspective, the Lean approach aims to complete each stage individually, for each unit, as close as possible to target processing time without having the excessive waiting. Problems in individual processing stations become immediately apparent and are quickly resolved. Thus the responsibility to improve no longer rests with an individual workstation. In manufacturing operations, all workstations must work together if the opportunity to solve problems is to improve considerably (Slack *et al* 2010).

Lean thinking implement methods, which seek to overcome this by introducing systems that process 'units', as an individual or family or group at a formulated rate. This approach aims to complete each stage, one at a time, for each unit as close as possible to target processing time without the excessive waiting, buffering and queuing times associated with current systems. In turn, this will eliminate waste and improve the passenger flow performance efficiency. Problems in individual processing stations become immediately apparent and must be quickly resolved. This means the responsibility no longer rests with operators of an individual workstation. Instead, all workstations must work together to considerably improve the chance of a problem being solved (Slack *et al* 2010). Thus airport departure will become a 'total' or 'holistic' process (Jackson 2003) consisting of processing stations or "components connected in an organized manner" (Wu 1994: p.30), which is how passengers view 'departure'. Thus emphasis is placed on the application of a systematic Lean methodology, which after the establishment of the objectives is able to identify, rationalise and optimise operational problems. (Checkland 1981, Jackson 2003).

However, given the special constraints created by externally-induced departure delays, different organizations' operators at different work stations, the lack of tangible and unified process control, strict international legal control of airport operations, and economic factors, all of which make airport operations entirely different from processes to which Lean has been previously applied. Therefore, the challenge is to turn airport departure into a 'total process' rather than a series of loosely-linked individual processes (Wu 1994) and able to operate in a dynamic, external environment.

2.6 An Alternative System View

Often representations in Lean systems are "*simplifications of a far more messy reality*" ….. which are ….. "*social systems, full of complex and ambiguous interactions*" (Slack, et al. 2010: p.291). The traditional analytical approach is normally based only on a functional perspective. This why most past researchers have focussed on modelling discrete parts of the process, as described in Section 3.2.1 and rarely have attempted modelling the entire passenger departure flow. Also, researchers have used specialist airport simulation software and have normally focussed on small regional airports (Roanes-Lozano, *et al.* 2004)

Airports which are almost entirely unlike manufacturing or situations such as healthcare (Burgess and Radnor 2013, T.P. and Mcclean 2010), software development (Al-Kaabi, et al. 2009, Tatum 2005) or service operations (Abdi, et al. 2006, Liker and Morgan

2006, Seddon and O'donovan 2010) where a single entity retains strong, direct control over flow within the process. The special nature of the passenger departure process means standard representations using flow and process diagrams inadequately describe the flow of passengers during departure. The external environment significantly affects the process overall as well every individual process related to process station. The ‘process’ defined in Section 2.2 does not adequately relate the passenger departure process to its dynamic environment. Systems theory provides such a perspective though strictly it is outside the scope of this research. It nevertheless provides a useful perspective if one is to fully understand passenger departure flow.

Wu (1994) defines a system is:

> *“a transformation process which converts a set of inputs into a set of outputs. The inputs and outputs of a system are the main interfaces between this system and the outside world”*(Wu 1994: p.29)

The hard systems methodology developed by Checkland (1981) offered a way of optimising the performance of a system in pursuit of clearly identified goals. In this research it simply offers examination of control in a different way. This means identifying the objective from a user’s viewpoint (Jackson 2003). From the customer’s perspective, the airport departure system converts a passengers desire to travel at a particular time and to a particular place into boarding the correct aircraft along with any luggage or goods they wish to carry using a series of individual processing stations.

Influences in the external environment ranging from major weather and volcanic activity may affect flights causing them to be delayed, rerouted or cancelled. Additionally, the travel industry and airlines like Etihad have developed systems facilitated by information and communications technology (ICT) which allow passengers to check in through various means (Adia 2011a, b) to reduce processing delays during check-in. The external environment remains uncertain both in terms of inputs and outputs where natural and terrorist events, local and perhaps many thousands of miles away can have an impact on aircraft departures and on internal processes (Slack *et al.* 2010). Flight delays, mechanical problems and other events beyond local control often create additional differences between scheduled departure time and actual departure time. It is important to note that research here is not investigating the effect of any external factors (mentioned above) on airport operations.

Thus while airport prescribe a standard time between check-in time and schedule departure - the ‘overall passenger departure process time’ in Figure 2-1, within certain broad limits passengers are generally free to determine when they enter any of the processing stations or progress between them. When entering the terminal individual passengers exercise choice over when to check-in either themselves or their baggage. They may use airport facilities before or after check-in and before entering processes that take them (normally) irrevocably across the boundary between landside and air side. Emigration and identification checks become the ‘point of no return’.

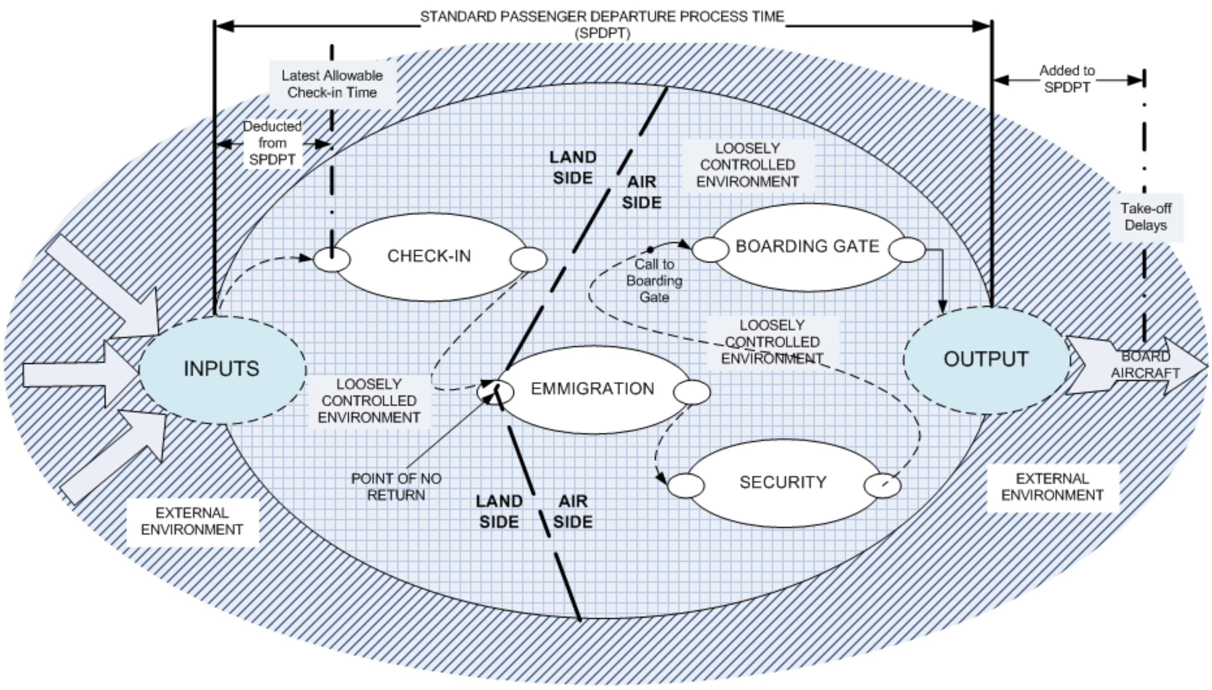

Figure 2-1 Simplified System View of Passenger Departure Flow

loosely derived from Wu (1994: p.33)

While early implementation of Lean in services generally tended towards a production-line approach (Bowen and Youngdahl 1998), with organisations adopting a standard, internal, cost focussed perspective this has proved far from satisfactory (Seddon and O'donovan 2010). It is unlikely that airline passengers would be happy to be treated like components on a production-line. The trend has been towards providing various facilities to enrich the airport experience for airline passengers and other users (Mei Ling, et al. 2010).

Within the loosely controlled environment airport authorities have deliberately created large-scale buffers deliberately to insulate processing stations from one another to improve passenger experience and to account for externally-induced flight delays (Mei Ling, et al. 2010). These add to the all-important quality of service for travellers and may affect their decision to use a particular airline or airport (Jin-Woo, et al. 2006, Mei Ling, et al. 2010) and so cannot be ignored. However, such arrangements are not for passenger benefit alone. They are also in place to fulfil certain economic needs and make airports financially viable.

Airports derive a significant part of their income from concessions, especially shopping and restaurants (Freathy 2004, Graham 2007, Kim and Shin 2001, Volkova 2003) and attempts to remove these deliberately installed buffers may meet severe opposition from airport operators. These revenues may vary in importance and size from one airport to another (Volkova 2003) from important to economically vital.

In reality, Lean improvements may not improve overall time spent in Departure Passenger Flow. Instead it will benefit both passengers and the Airport Authority by allowing them to spend less time in compulsory operations (such as check-in, emigration and security) at processing stations and greater time in the more enjoyable parts of the airport.

2.7 Characteristics of Departure Passenger Flow.

The full departure process involves managing passengers through several stages, ensuring perfect accuracy and delivering them to the boarding gate at the appointed time. The research has identified the following key characteristics each of which has an impact of the passenger flow process:

1. **Accuracy**: from a passenger flow perspective, accuracy means a perfect check-in, error-free security; correct ticketing and delivery of the right number of people to the right flight, no matter what variations to actual departure time, security conditions, or unforeseeable operational difficulties may occur (Bittel, *et al.* 2007).

2. **Different Passenger Units**: Passengers may arrive as an individual, family or group, each of which will affect the processing time of individual 'units' (Bittel, *et al.* 2007). Passenger class, age and disability will also affect queuing and processing time.
3. **Transit passengers**: Transit passengers are passengers arriving by air who transfer to another aircraft through part or all of departure facilities. The extent of use of facilities depends on the types of transfer, how the airport is configured and particular airline services used (De Barros, *et al.* 2007).
4. **Short Response Times**: All passengers regardless of their characteristics want to wait at any processing station only for the shortest possible time (Mei Ling, *et al.* 2010).
5. **Simplicity**: The boarding card issued at check-in provides access to each of the following processing stations for typical passengers. Other processing stations may require additional documents (Van Dijk and Van Der Sluis 2006).
6. **Flow of Information**: The boarding card provides the limited information flow the process requires. Individual processing stations use other specialised information provided by their own national and international IT systems (Bittel, *et al.* 2007).
7. **Overall Information Flow**: There is no overall flow control and each major processing station is linked only to the station operator's computer system. Data management is entirely separate with airlines, security services and airport operators each having their own international or national IT system (Bittel, *et al.* 2007). Consequently paper 'documents' form an important part of the process. From the check-in stage until the departure gate, the passenger's passport and boarding card become the two primary documents which provide the means of checking identity and recording progress at each work station and as a security control against passengers going missing at any stage, including departure.
8. **Synchronisation** Non-synchronised processes attempt to encourage efficiency by protecting each part of the process from disruption. Synchronisation takes the opposite view. In airport processes there may be a need for synchronisation between the workstations. The process is developed by identifying constraints and bottlenecks within the system and eliminating waste. Exposure of the system leads to transparency which makes problems more immediately apparent. This compels

people to improve poorly performing elements within the chain of processes this led to Slack's definition that "Lean synchronisation aims to meet demand instantaneously with perfect quality and no waste" (Slack, *et al.*, 2010: p.432).

9. **Check-in Time-Window:** passengers are told by the airline to "report to check-in 'h' hours before scheduled departure time". 'h' hours is normally part of a 'check-in window' which states earliest and latest check-in time. The check-in time-window is decided collectively by the different operators depending on various operational factors which include security needs which govern how long the slowest passenger will take to pass through the process. Because of the need for increased simplicity and certainly through standardisation of check-in times before departure, this translates into 'the time the slowest passenger takes to pass through the system in the slowest departure process for any aircraft by airline' (Psaraki-Kalouptsidi 2010). Thus, for example, the standard check-in time for Etihad Airways in Abu Dhabi Airport is four hours before scheduled departure. Smaller airlines operating from the same airport offer three or three and a half-hour check-ins (Etihad Airways 2011).

   - **Visual In-terminal Instructions to Passengers:** After arriving at check-in during a predetermined time-window, typical passengers move through the process at their own speed. Information about departure times are transmitted to passengers through visual display terminals (Singh and Kumar 2006). These also tell passengers which processing station to visit next, based on current information about departure time. Only in the case of call to the departure gate are passengers directly pulled through the system, normally by the airport's visual displays of departure progress (Bittel, *et al.* 2007, Singh and Kumar 2006).

10. **Sensitivity**: As an international operation, staff at each of the processing stations must exhibit national cultural and religious sensitivity to each nationality passing through the Abu Dhabi. This extends to the different ways in which male and female passengers are processed (Graham 2007).
11. **Operators**: Each workstation is run by different "*operators*", usually the airline, state security and border control services, and the terminal "operator".

12. **Legal Framework:** There are strict legal limitations on the activities which *must* take place in the process used at each processing station, which vary from time to time and most of which are aimed at aircraft security (Bittel, *et al.* 2007). These limitations are imposed by international and national aviation and security laws, rules and regulations on airlines and airport operators including those made by the International Civil Aviation Organization (ICAO), the International Transport Association (IATA). Rules also include those set under Aviation Security Conventions including the Chicago Convention 1944, the Tokyo Convention 1963, The Hague Convention 1970, the Montreal Convention 1971 and Protocol 1988, the Marking of Plastic Explosives(MEX) Convention 1991 and others (Graham 2007). Nationally, each country including has to implement international standards taking account national laws, also. Such laws, rules and regulations relate directly to the management, supervision and control of processing stations. Any Lean optimisation must take account of them because they may seriously interfere with normal method of process improvement. These will normally be formalised in the form of an 'Airport Security Master Plan'. They cannot be ignored.

While certain characteristics are outside the consideration of this research in practice, this research directly addresses the following characteristics:

- **Different passenger units:** because these have a potential effect on processing time at work stations, especially in check-in;
- **Transit passengers:** because they have a different route through the system and only join the common flow at the boarding gate;
- **Short response times:** because this is the principal measure of interest to both passengers and the airport authority;
- **Synchronisation:** because of its direct effects on identifying constraints and eliminating bottlenecks;
- **Operators:** because of their effects on processed time in each processing station.

2.8 Flow of Passenger at Departure Process

The **airport departure process** consist of a number of completely separate groups of workstation where ‘*potential* passengers’ are transformed into ‘*originating*’ (approved departing) passengers’ through a series of workstation.

These ‘groups’ include:

a. Check-in (Ticket counter and baggage deposit),
b. Immigration control (Ticket screening /border control),
c. Security screening,
d. Departure lounge,
e. Boarding control.

2.8.1 Departure Processes

Check-in customisation: The principle purposes of check-in is to receive baggage and to give boarding cards to passengers, and to carry out certain duties imposed on airlines by national and international laws (Bittel, et al. 2007). Although an alternative remote option is increasingly provided through the internet by major airlines, a typical passenger presents his passport and ticket at check-in (Van Dijk and Van Der Sluis 2006).

Traditional [In-Airport]: This is carried out by the Airline or their Handling Agent. Passengers are typically streamed into ‘classes’ depending on the type and size of the aircraft. For passenger, the Airline checks tickets and identity; receives, weighs and security seals luggage; and checks that passengers have relevant documents to enter the country of destination, the luggage has been packed by the passenger, and luggage does not contain prohibited material (Bittel, et al. 2007). After baggage is weighed and transferred to handling conveyors, the passenger is given additional documents in the form of a boarding card, and a receipt for baggage appended to his ticket. Passengers with special luggage requirements such as long or bulky items, dangerous items or overweight baggage are screened out and sent to other special counters.

The type and scope of information required at check-in is destination specific, because each country will impose its own special visa and passenger information requirements

(Graham 2007). The airline also checks if Advance Passenger Information (API), required by a small number of countries including the USA, has been received on time. Allocation of seating and requests for special dietary needs are handled at check-in (Bittel, et al. 2007).

Remote Check-in: Some, but by no means all airlines have introduced check-ins which may be carried out remotely over the internet or mobile phones for typical passengers; those who do not have special documentation or luggage needs. The Remote Check-in system may also be used to provide API. Facilities may be offered to allow passengers to choose their seat or special dietary requirements. Passengers complete this process by using automated bag check-in at the airport (Adia 2011b). Unusually in Abu Dhabi, in-town check-in is provided principally for passengers of Etihad Airlines where passengers may check-in luggage at designated centres before travelling to the airport.

Emigration (Passport Control): This group of workstations check that a passenger’s passport is valid for the duration of his/her trip or for any period set down by the destination country. Border Control Officers also check that visa, transit and ongoing entry requirements are in order. Only UAE citizens or those holding valid UAE residence visas may use the alternate eGate service (Adia 2015a).

Security: Passengers and their hand luggage are checked in security processing stations. The stations check for compliance with international regulations for items carried, hand luggage and personal possessions are x-ray screened and electronic devices such as laptops and tablets are separately monitored. In the first initiative of its kind in the entire UAE, dedicated facilities exist for security checks for veiled female passengers (Adia 2015b).

Departure Lounge and Boarding Control: Display screens summon passengers to the departure lounge, at a predetermined time before aircraft departure. Shortly afterwards, and a predetermined time before actual airport departure, the boarding control processing station opens to check passengers are available for boarding the aircraft using boarding cards and passports. This group of processing stations also checks for passengers who have checked in but who have not presented themselves at the boarding gate on time (Adia 2015b).

2.8.2 Different Types of Buffers:

1. **Station Buffers**: Each stage in the process places its input in a queue in front of the processing station. This 'buffers' the stage from next one downstream in the process (Narens 2004).

2. **Facility Buffers**: Output is further buffered within airport facilities (Figure 2-2). To make delayed departures more acceptable, airports usually create large facilities containing concessions in which passengers can spend time (Bittel, *et al.* 2007). Here passengers wait to be called to the next processing station (Singh and Kumar 2006). Understanding the constraints caused by these holding areas, linked to the inevitable changes in many departure times and the variability among passengers is fundamental to this research because buffering areas cannot be removed in the way one might expect to remove them in a manufacturing enterprise, for example.

2.9 Departure Passenger Flow Process Mapping

While airports worldwide have adopted methods of dealing with security concerns and increasing complexity, it is clear that growing competitive pressures to become effective and efficient compel many other service industries to adopt the Lean philosophy. As Abdi, et al.(2006) observe, a Lean approach is not about a collection of tools applied mechanically to problems.

Figure 2-2, presents the simplified form of a generic process flow in the form of process mapping. The flow chart differs from the value chain in traditional processes because value chains include the complete activities involved, whereas the value stream refers only to specific parts of the organization that actually add value to the service being considered (Hines and Rich 1997). The rationale behind mapping is to help identify waste in individual value streams. Once identified, an appropriate route to the removal or reduction of waste within the process can begin. The flow chart shown in Figure 2-2 represents a simplified version of an entire generic departure process of the type found in most major airports. Chapter 4 will chart and examine the particularities of flow in Terminal 3 of Abu Dhabi Airport.

Practically, this research carries out a preliminary analysis of the process and then follows this by recording in detail all the items needed in each process. Each step will be categorised in terms of the variety of activities types such as operations, inspection, transport and storage.

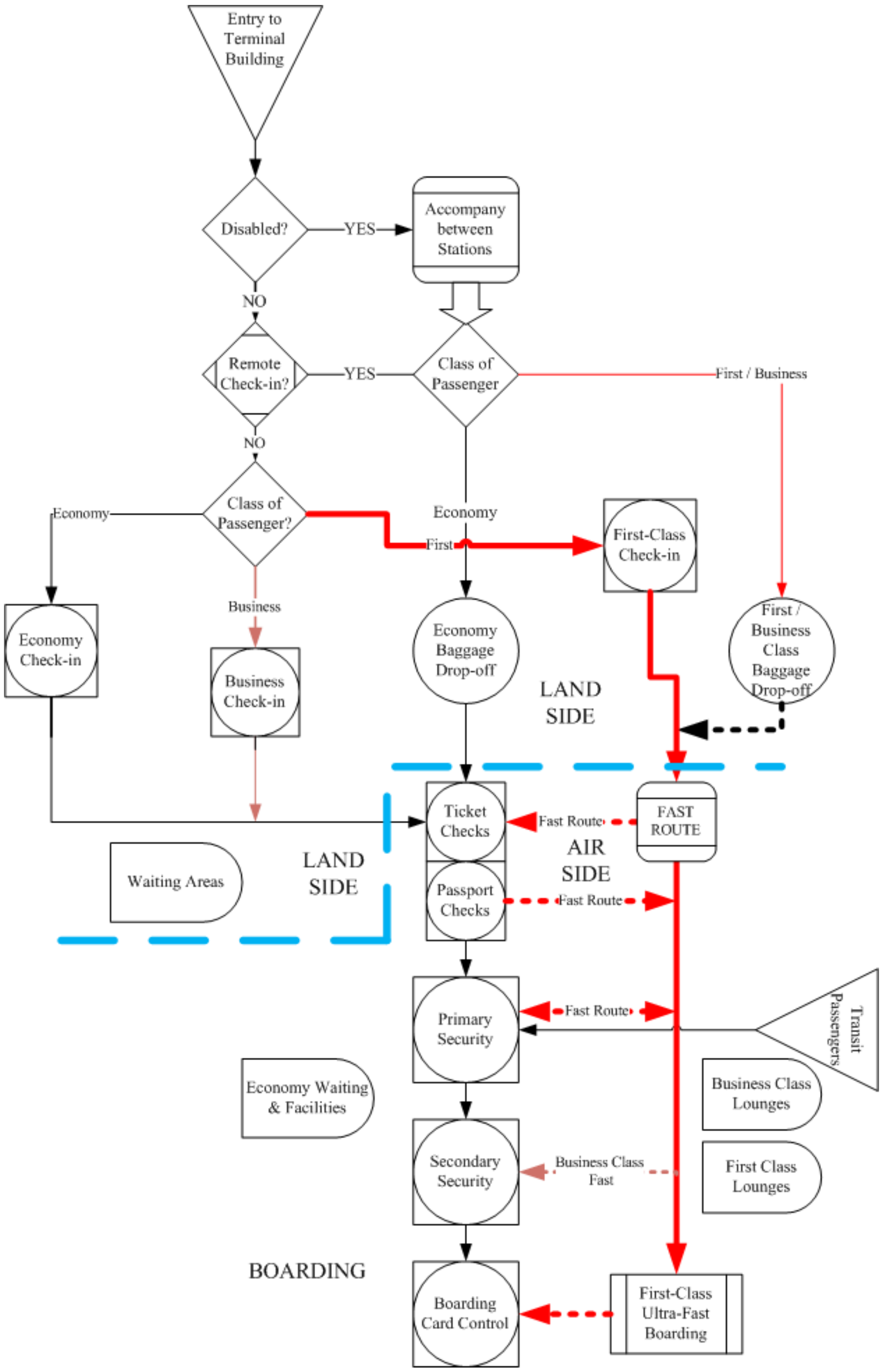

Figure 2-2 Generic Passenger Departure Process Flow (simplified)

Derived from: Graham (2007)

Following the construction of the chart; total distance moved, time taken and people involved is calculated and recorded. Researchers undertaking this process create a problem-solving framework(Hines and Rich 1997) which questions and evaluates:

1. **Why** does the activity take place?
2. **Who** does it?

3. On **which** equipment is it done?
4. **Where** is it done?
5. **When** is it done? And
6. **How** is it done?

The analysis process described by Hines and Rich (1997) is aimed at manufacturing operations. With suitable adaptation, a similar process may be used to map the departure flow process, both entirely and at each processing station.

The term 'process mapping' describes processes in terms of how the activities within the process and how they relate to each other (Slack et al, 2010). Each process represents different types of activity take place during the process and show the flow of people or information through the process (Slack et al, 2010). These diagrams allow each activity to be systematically challenged during process improvement.

Detailed process maps are shown for the entire passenger departure process and each processing stations in Chapter 4.

Several variations on methods proposed by Hines and Rich (1997) have been proposed by Tapping, *et al.*(2002), Nash and Poling (2008), Slack, et al.(2010) and Borris(2012). While each is broadly similar, they vary in method rather than substance. In this research, each method will be assessed to decide the appropriate method of presenting data once mapped. Such clear presentation is vital because the end-to-end system mapping that value stream mapping (VSM) involves must be capable of showing not only the direct activities involved in each and every process, but should also show the indirect information systems that support the direct process (Slack *et al* 2010). They also point out that VSM involves working on and improving 'the big picture' as a first step to recognising and improving system waste.

2.10 Chapter Summary

This Chapter defined the characteristics of passenger flow during the departure process using widely accepted definitions. It went on to describe the theoretical basis behind the most important concepts underlying the Lean philosophy. It described briefly how system theory could be used to show the important relationship between the passenger departure process and its environment. The Chapter then showed how the Lean philosophy could be applied to the departure process in airports and examined how this research will use theoretical Lean principles and performance measurement towards the practical achievement of improved flow characteristics of the reduction in variation. The next Chapter evaluates airport modelling.

Chapter 3 : Airport Modelling

3.1 Overview

This Chapter examines the nature and formal approaches towards problem-solving in an airport departure environment. It focuses on identifying airport passenger flow and related issues in existing departure models in the literature.

3.2 Existing Models of Passenger Departure Flow

3.2.1 Approaches to Passenger Departure Flow

Various authors have taken different approaches to describing passenger departure flow. In most cases researchers have recognised the special and discontinuous nature of passenger flow and have often concentrated on single types of processing station. Others have accounted for different responsibilities among different legal entities operating different workstations (Ashford, et al. 2010). The most common are check-in (Chang and Yang 2008, Parlar and Sharafali 2008, Van Dijk and Van Der Sluis 2006), and security (Bittel, et al. 2007, Kaffa-Jackou, et al. 2009). Departure gate studies normally focus on scheduling of aircraft to different gates (Dorndorf, et al. 2008, Edwards and Newell 1969, Peterson and Bertsimas 1995) rather than necessarily the flow through gates themselves.

Jim and Chang (1998), Roanes-Lozano, *et al.*(2004) and Rauch and Kljajić(2006) have exceptionally investigated flow through the whole departure process. Each uses simulation as essentially the only tool for assessing airport operations without recourse to external theory such as Lean. While the current research mirrors that of these three papers, they are nevertheless of limited value because of significant differences in their airport environments and the application of Lean and Taguchi methods in this project.

Jim and Chang (1998) developed a simulation model using SLAM, a dedicated airport modelling program that has been necessarily simplified. The model assumptions make it of limited value, certainly from the Lean analysis point of view. They have assumed that passenger and processing facilities are always similar and independent of airport type and location (Jim and Chang 1998). The researcher does not agree this is the case and instead believes designers and airport operators strive to create unique facilities which reflect the characteristics of the country in which they are found. Jim and Chang

(1998) note they have modelled transfer passengers, which are a special feature of major international hubs passengers Abu Dhabi, by using random numbers rather than any detailed modelling of the process. One of the assumptions was that passengers proceed directly from one processing station to another which rarely happens with most passengers. Finally, Jim and Chang (1998: p.390) suggest the flight schedule "*provides a time varying demand on the landside*" and that it is the schedule rather than actual departure time which generated or simulated passengers. These authors neither take into account various important characteristics of passenger flow (Such as group size, passenger classes, etc. as described (Section 3.4.3) nor the current complexity of systems developed using technology or that have been stimulated by a much greater awareness of the need for international air security since the events of 9 September 2002 in New York.

Unlike Jim and Chang (1998) who suggested airports were inherently similar, Roanes-Lozano, *et al.* (2004) used simulation with Maple 8 to model Malaga airport in Spain which they recognised was somewhat different to the norm, with its specially high volume of charter airline holiday traffic, particular physical constraints and “*not very common*” (2004, p.164) unseparated facilities on each side of the line separating airside from landside and with unseparated emigration and airport security workstations because of the high number of passengers travelling within the EU, and especially in the Schengen area. The aim of Roanes-Lozano, *et al.* (2004) study was to develop a dedicated simulation model for Malaga.

Rauch and Kljajić (2006) also simulate departing passenger flow using simulation, though in this case developed a special model using General Purpose Simulation System (GPSS) in a small regional airport, unlike Abu Dhabi Airport. The primary objective of their study was to identify bottlenecks and study alternatives during peak operations. Despite the differences in both the airport environment and the aims of this research, Rauch and Kljajić’s (2006) techniques provided a useful foundation for this research.

Other researchers have examined the aspects of the departure process such as capacity planning (Gelhausen 2009, Jim and Chang 1998, Ming-Miin 2010, Solak, et al. 2009) or external issues which affect passenger arrival at the departure terminal. Yet more researchers have looked at issues such as perceived quality of service (Jin-Woo, et al. 2006, Mei Ling, et al. 2010, Oppermann and Cooper 1998), an important aspect of Lean (Hagemeyer, *et al.* 2006, Liker and Morgan 2006, Seddon and O'donovan 2010, Slack, *et al.* 2010)

As this section (3.2.1) shows other researchers have opted for various different methods from those chosen for this study because of the particular circumstances they faced, almost always in small regional airports. This study considers the operations of a major international hub. Of these, this researcher considered that simulation provided the most practical means of verifying lean theory in the particular environment found in Terminal 3 of Abu Dhabi Airport. Thus, after consideration of the literature, this research used discrete event simulation approach to model the ADIA departure passenger flow as described in Section 5.6 using the proprietary Simul8™. This is described in greater detail in Section 5.5.

3.3Existing Models of Control in Departure Flow

3.3.1 Task Division of Process Control and Management

A defining characteristic of the passenger departure process is that it is dissimilar to manufacturing or service processes to which Lean has previously been applied. This arises because each processing station and facility is under different control (Graham 2007). This changing focus of control occurs throughout the departure process because of the special nature of airport terminals generally. Kellerman (2008) describes an airport terminal as an "*environment of authorities*". To add further complication, the environment is different when viewed from the perspective of various involved parties such as airport management bodies, regulators, governments, commercial operators and suppliers as well as the most critical group, passengers. Figure 2-1 shows the impact of the external environment factors such as change in international regulations; weather has an impact on the inputs and output of the passenger departure flow. Indeed, the airport has become "*the most authoritarian facility designed for the use of free citizens by the wider base, amount, domain and scope of authority powers*" (Kellerman 2008, p.166). Such authorities may be international, national, local and commercial. The environment is at the same time 'authoritarian' issuing orders to passengers which must be obeyed automatically and 'authoritative' when it comes to governing the flow of passengers with its various rules and regulations. International terrorism has also had a significant effect on flow. Gordon, (2004, p.238) describes this effect as "*anti-terrorist measures* [*which have*] *turned the airport into an electronically controlled environment rivalled only by the maximum security prison*".

Within the limits of the time envelope set by airlines based on scheduled departure time, originating passengers may mostly move in their own time between one processing station and another, even though they must follow a particular sequence of workstations. In the case of Terminal 3 of Abu Dhabi Airport, the time envelope is four hours (Adia 2011a) from check-in time to scheduled departure time. Most flights have their departure delays by various factors, some of which are outside local control. These factors may include weather, local, national and international air traffic control, international security issues and mechanical problems with aircraft. Often, a delay at a previous airport has a knock-on effect on actual departure time.

Most airports have installed intermediate facilities. Intermediate facilities fulfil important functions which grew from the inherent uncertainty of aircraft arrival and departure times. Transfer passengers may have even more hours to spend in the airport depending on the timing of connecting flights.

Now intermediate facilities have taken on another function. Shopping, especially duty-free shopping, restaurants and cafes and other activities were found to be not only methods of occupying passengers and reducing passengers stress (Volkova 2003) but as valuable revenue-earners for the airport (Vojvodić 2008). The income that franchisees provide for airport have now became so valuable that over a period they became incorporated into airport economic and financial models. Without these sources of income, many airports simply could not operate (Freathy 2004). Consequently, it is in an airport's interest to encourage passengers to linger as long as possible in intermediate facilities, which are present both on both landside and airside (Volkova 2003).. This is an important consideration when considering Lean operations because the focus is not taking passengers as quickly as possible through the system, but rather reducing 'necessary' time at processing stations and freeing passenger time to use intermediate facilities (Volkova 2003). In recognition of economic reality, international Airport Service Quality (ASQ) system of quality assurance operated by ACI, measures check-in, passport control, security check, transfers services and boarding and effectively ignores intermediate facilities from the standpoint of time.

In manufacturing and most service operations there is a basic choice between push and pull systems (Slack, *et al.* 2010). Arguably, scheduled departure time creates a pull-system which draws originating passengers into the airport, before the defined passenger departure process. The only place where a pull-system operates during the defined departure process in many airports is the final stage. In most airports passengers are summoned to the departure gate by the likely time of aircraft departure, which may be different from the scheduled departure time. Passengers are often sorted by characteristics such as 'families with children', by class or scheduled aircraft-seating position before final boarding.

Readers should note at this point, this thesis uses the term 'buffer' in a less specific way than its normal sense as a safety stock (Section 3.6.1) in preference to the manufacturing term 'inventory'. Inventory as a term defined by Slack et al (2010) as "*the stored accumulation of* [passengers] *in a transformation system*" is strictly correct, though a rather inappropriate term to use when describing people.

Abu Dhabi Airport's Terminal 3 uses a three-stage approach before final boarding. The first stage uses information screens which push passengers towards a buffer area immediately in front of the departure gate based on *scheduled* departure time. In the second stage, a pull-system draws passengers through the departure gate where documents are checked. This stage uses *actual* departure time to send passengers into a second buffer area immediately in front of the boarding gate. In the third stage passengers are summoned by characteristics such as 'families with children' or passenger class to go through the boarding gate to board the aircraft.

From this perspective, the passenger departure process resembles a supply chain (Lamming 1996, Slack, *et al.* 2010) more than a simple end-to-end manufacturing or service process. In the supply chain model, various workstation operating entities become 'partners' in the process. Slack et al (2010) describe such partnership arrangements as a compromise between vertical integration where the resources are wholly owned by one 'partner' and pure 'market relationships' only responsible for transactions. Thus in the airport departure process operators cooperate to a limited extent over which flows and linkages occur for the joint accomplishment of the departure process. Ideally, a close partnership arrangement is influenced by a number of factors including:

1. Sharing success;
2. Long-term expectations;
3. Multiple points of contact;
4. Joint learning;
5. Joint coordination of activities; and
6. Joint problem-solving (Slack et al, 2010).

Ultimately, the Airport Authority acts as a co-ordinator which can request or order particular actions by overall workstation operators. This normally occurs when it is necessary to relieve congestion or in connection with airport security. The Airport Authority is also the main deliverer of customer relations management (Slack, *et al.* 2010) which, as well as providing customer service also examines ways to increase efficiency, enforce standardised processes and take an overall view of airport operations.

3.3.2 Special Features of Queuing Within the Departure Process

Passengers moving through the departure process may be subjected to queuing and various delays. Often these are because of capacity and resource constraints in various parts of the process (Jim and Chang 1998). Capacity constraints may be associated with various factors These include an increase in numbers of passengers; daily, weekly, monthly or seasonal traffic flow distributions (Narens 2004, Van Dijk and Van Der Sluis 2006); increased security; shorter connection time for the transfer passengers; service availability at various workstations created by limited equipment or service personnel; or the need to better use of assets (Rauch and Kljajić 2006). Other causes include limited equipment or human agents (Olaru and Emery 2007, Rauch and Kljajić 2006, Van Dijk and Van Der Sluis 2006). Passenger flow may also be affected by the size of aircraft or the particular destination (Jim and Chang 1998, Roanes-Lozano, et al. 2004) or the earliness distribution of passengers arriving at any of the processing stations (Narens 2004, Olaru and Emery 2007). Taken together, these potentially create considerable variability.

Slack et al (2010) notes that such variability results in either passengers waiting to be processed, idle processes, or significant changes to average waiting time and process utilisation. Only some of this variability can be predicted because of the effect of external influences on departing aircraft. This make any attempt to smooth passenger flow through the departure process increasingly difficult especially constraints are imposed by a fixed physical layout, limitations of available resources, or the process depends on a single workstation. The latter occurs in ‘excess baggage’ or ‘special items’ processing.

Various airports use different queuing systems such as processing stations dedicated to particular flights. Other airports, including Abu Dhabi use common-use queuing (also known as ‘Disney queues’) to hold passengers in a single queue for several workstations and then distribute them as individual workstations become free from time to time (Parlar and Sharafali 2008). Some airports extend the common-use where passengers irrespective of their flight may use any processing station. This system is most usually found in check-in, emigration and security. This method is used in Terminal 3. Common-queue systems lead to higher utilisation of resources (Parlar and Sharafali 2008).

3.3.3 Existing Means of Analysing the Departure Process

Literature relating to queue management and process flow is limited especially in relation to passenger departure flow in airports (Parlar and Sharafali 2008). On the ground, this has led to various methods of queuing management including deliberate over-provision of processing stations; *ad hoc* methods of opening service counters and processing stations; use of simulation to develop more accurate models of bottlenecks and flow; to rule-based algorithms. For the last, the most common algorithm models are based on Markov or semi-Markov statistical models which use probability theory to create a stochastic process capable of predicting flow (Cheng-Lung and Caves 2004, Meirina, et al. 2008, Parlar and Sharafali 2008, Peterson and Bertsimas 1995).

Bittel, *et al.* (2007) and Kaffa-Jackou, *et al.* (2009) both used statistics-based analytical models. Bittelet et al.*(*2007) used them when evaluating the impact of Aviation Security Policies on passengers and airlines. Kaffa-Jackou, *et al.* (2009) focussed on internal security operations to better enable efficient allocation of equipment and work teams and minimise the possibility of dangerous situations, this was achieved while simultaneously maintaining minimum levels of service quality.

Majeske and Lauer (2011) developed two Bayesian decision models to analyse security workstations. These authors used a single stage model to aid the original computer-assisted passenger pre-screening system. They also employed an improved two-stage model which used pre-screening techniques to filter out potentially high-risk passengers and thus significantly reduce bottlenecks at security workstations.

Each of the authors describe in the previous two paragraphs provide a useful insight into the security process. Nevertheless the improvement methods they propose are outside the scope and purpose of this research because this research is not focusing on security process only.

3.4 Types of Flow

3.4.1 Effects of Passenger Class on Process Design

The passenger departure process is driven by both operational needs and the needs for compliance with local and international laws. Consequently, the process contains essentially the same actions each class of passenger; first, Business-Class and Economy-Class. Nevertheless, each class of passenger has different expectations of their treatment under the process depending on the cost of their travel (Roanes-Lozano, et al. 2004). Airlines and airport authorities respond to those expectations by separating the three classes during departure (Jim and Chang 1998).

Typically, airlines charge international Business-Class passengers between four and seven times more than Economy-Class passengers. First-Class passengers are normally charged around three times the fare of Business-Class passengers. While much of the cost is accounted for by in-flight service and accommodation aboard the aircraft, treatment aimed at reducing queuing and waiting time at every processing station during both arrival and departure processes. When waiting is unavoidable, better accommodation in the form of improved waiting areas is provided. Some airlines have dedicated terminals for First-Class passengers and separate lounges for Business-Class travellers (Jim and Chang 1998).

The airlines' and airport administrators' solution has been to separate each class into parallel processes so each enjoy the service level, facilities and levels of available resources appropriate to their class (Rauch and Kljajić 2006). To ensure speedier and more efficient service at the airport, baggage handling arrangements are separate, faster security lanes are in operation and check-in counters are more numerous and better resourced than Economy-Class passengers.

This research will simulate the economy, first and business class flow for the departure process. The simulation model is generated (layout and associated timings) based on the data collected form Abu Dhabi international airport terminal 3.

3.4.2 Flight-Related and Continuous Flow

Flight schedules are fixed many months in advance. They contain periodic changes in demand whether by the season, week of the month, day of the week (Rauch and Kljajić 2006, Roanes-Lozano, et al. 2004, Van Dijk and Van Der Sluis 2006) or hour of the day (Narens 2004) resulting in a complex pattern of changing demand even without the disruptive effect of internal and external delaying factors. Internal factors include aircraft breakdowns (Olaru and Emery 2007), general and aircraft specific security problems and so on. Destination characteristics may be an important influence on passenger characteristics in such matters as the amount of luggage carried (Rauch and Kljajić 2006). Examples observed in Terminal 3 included flights between Gulf Cooperation Council (GCC) states where the percentage of business travellers, even in Economy meant a higher proportion of hand-baggage only while travellers to the Hajj were appreciably different from those going to recreational holiday destinations. External factors are varied and include weather and atmospheric conditions, time of aircraft departure from previous airport, local, national and international air traffic control problems and so on.

Other factors which potentially create variations in passenger flow include aircraft types, total passengers per flight, load factors (Roanes-Lozano, et al. 2004) and intervals between flights (Olaru and Emery 2007) or destination characteristics (Rauch and Kljajić 2006).

When improving manufacturing flow, planning or operational managers attempt to remove variations, most of which are local and internal and achieve smooth, uninterrupted flow using control of inventories and work-in-progress or exponential smoothing (Slack, *et al.* 2010). Using flight schedules of departure times is closely akin to forecasting using qualitative methods like scenario planning (Slack, *et al*. 2010) or qualitative methods. Scheduled variations, no matter how complex are rather easier to account for even though they result in considerable variations in the daily flow. In the latter time-series analysis is possible to remove underlying variations with assignable cause extrapolation techniques to predict behaviour (Slack, *et al*. 2010). Knowledge of past events permits the forecasting of on assignable variations but given that external factors are considerably more variable than in manufacturing or service industries because of the very nature of flight this has somewhat limited applicability.

Airport authorities have generally chosen to methods of dealing with flow variation. Traditionally, some resources such as check-in or departure counters allowed passengers to select a queue in which they remain until processed. More recently, common-use ('Disney') queuing, previously only applied to security and passport control is now applied to all processing stations throughout the terminal (Olaru and Emery 2007). This provides improved flow to each workstation at periods when queues (buffers) are occupied by allowing passengers to be summoned immediately to the next available resource.

Traditionally also, certain resources such as check-in desks are allocated to individual flights (Roanes-Lozano, et al. 2004). Terminal 3 in Abu Dhabi has taken Disney queuing to the next logical level and individual check-in desks are not normally allocated to specific flights. Instead, passengers entering the departure process go to a common-queue for all flights.

However, taken as a whole and because of the large concessionary areas set aside between groups of processing stations which act as major buffers, passenger departure flow cannot be said to resemble continuous flow in the sense normally described in manufacturing or service operations. Nevertheless, this research will show that there exist possibilities to create continuous flow between and among the various groups of processing stations.

3.4.3 Effects of Passenger Group Size

Little attention has been paid to the effects of passenger group size by other researchers. Jim and Chang(1998) noted the existence of group size but did not expand further on this. Olaru and Emery(2007) took a different approach and made group/family size an automatic attribute associating it with the purpose of the travel. They noted that groups of holidaymakers are "*likely to have more luggage and in consequence higher service rate*" (Olaru and Emery 2007, p.5).

In Terminal 3 and informally in other airports, this research has noted the general effect of group size. While agreeing that those with more luggage may have a higher service rate, it was observed that in most cases of travelling groups, especially family groups and organized groups service time tended to be quicker, not slower, because one member of the group, either a parent or group organizer normally took charge and eased the process for the rest of the group in most or all processing stations. Consequently, when simulating passenger movement, a decimal factor was used to increase passenger service rate per person for those travelling in groups. For simulation purposes, this research uses the passage group size of 1, 3 and 8 as observed from ADIA.

3.5 Variability Related to Passenger Departure Flow

Various researchers including Roanes-Lozano, et al (2004), Rauch and Kljajić(2006) and Olaru and Emery (2007) identified some sixty-two factors relating to variability in passenger departure flow (Table 3-1).

Careful analysis allowed this researcher to reduce the number of variables to the forty-one shown in Table 3-2. This number was further condensed to factors which could be used by the simulation program, Simul-8 (Section 5.6)

Variability in manufacturing is considered a problem, sufficient enough to attract planners to reduce the effect of normal variation because such variation masks any changes in process behaviour affecting performance (Slack, *et al.* 2010). Thus identifying variables provide greater knowledge of exactly how the process works.

Table 3-1 Variables Identified in the Literature

Variable	Process	Context	Tool	Type
Capacity of Service Facilities	Various	Flow	Simulation	Quantitative
Passenger Class	Various	Characteristics	Simulation	Unordered Categorical (Qualitative)
Domestic or International	Various	Flow	Simulation	Binary - Quantitative
Flight Schedule	Various	Flow	Simulation	Time Data
Choice of Supplementary Facilities	Intermediate Holding Areas	Flow	Simulation	Unordered Categorical (Qualitative)
Foreigner/Local	Various	Security	Simulation	Binary - Quantitative
Baggage Problems	Check-in & Security	Passenger Processes	Simulation	Binary - Quantitative
Aircraft Type	Various	Flow	Simulation	Unordered Categorical (Qualitative)
Total Passengers per Flight	Various	Flow	Simulation	Quantitative
Boarding Card Number	Various	Passenger Processes	Simulation	Unordered Categorical (Qualitative)
Percent Pre-ticketed	Check-in	Characteristics	Simulation	Quantitative
Passenger Group Size	Various	Characteristics	Simulation	Quantitative

Variable (cont'd)	Process	Context	Tool	Type
Security Time Distribution	Security	Flow	Simulation	Statistical
Number of Processing Stations	Various	Flow	Simulation	Quantitative
Service Rate	Various	Flow	Simulation	Quantitative
Service Distribution	Various	Flow	Simulation	Statistical
Waiting Time	Various	Flow	Simulation	Generated Output
Queue Length	Various	Flow	Simulation	Generated Output
Animated Movement	Various	Flow	Simulation	Animated Output
Virtual Queue?	Various	Flow	Simulation	Binary - Quantitative
Earliness Distribution	Check-in	Flow	Simulation	Statistical
Time of Day	Various	Flow	Simulation	Quantitative
Travel time to Departure Gate	Departure Gate	Flow	Simulation	Quantitative
Time Between Simulations	Various	Passenger Processes	Simulation	Quantitative
Charter or Scheduled	Various	Passenger Processes	Simulation	Binary - Quantitative
Arrival Distribution	Check-in	Characteristics	Simulation	Statistical
Assigned Flight No.	Check-in	Characteristics	Simulation	Qualitative
Assigned Check-in Time	Check-in	Characteristics	Simulation	Quantitative
Queue Length Check-in (Determines Queue Taken)	Check-in	Flow	Simulation	Qualitative
Shared/ Dedicated (to Airline) Counter	Check-in	Flow	Simulation	Binary - Quantitative
Shared/ Dedicated (to Specific Flight) Counter	Check-in	Flow	Simulation	Binary - Quantitative
Minimum Walk Time Between Processing Stations	Various	Flow	Simulation	Quantitative

Variable (cont'd)	Process	Context	Tool	Type
Daily Traffic Flow Distribution	Various	Flow	Simulation	Quantitative
Percentage of Delayed Passengers At Departure Gate	Departure Gate	Flow	Simulation	Quantitative
Annual Departures	Various	Flow	Simulation	Quantitative
Monthly Departures	Various	Flow	Simulation	Quantitative
Weekly Departures	Various	Flow	Simulation	Quantitative
Late Arrival?	Check-in	Flow	Flow Chart/simulation	Binary - Quantitative
Has Bags?	Check-in / Transfer	Passenger Processes	Flow Chart/simulation	Binary - Quantitative
Sufficient Time for Process?	Various	Passenger Processes	Flow Chart/simulation	Binary - Quantitative
Use of Supplementary Facilities?	Various	Flow	Flow Chart/simulation	Binary - Quantitative
Use of Boarding Gate?	Boarding Gate	Passenger Processes	Flow Chart/simulation	Binary – Quantitative
Transit Passenger?	Various	Passenger Processes	Flow Chart/simulation	Binary - Quantitative
Boarding Time	Boarding Gate	Passenger Processes	Flow Chart/simulation	Quantitative
Load Factor %	Various	Flow	Flow Chart/simulation	Quantitative
Average Waiting Time in Queue	Various	Flow	Simulation	Generated Output
Maximum Waiting Time in Queue	Various	Flow	Simulation	Generated Output
Service Occupancy	Various	Flow	Simulation	Generated Output

Variable (cont'd)	Process	Context	Tool	Type
Service Availability	Various	Flow	Simulation	Generated Output
Destination Characteristics	Various	Passenger processes	Simulation	Unordered Categorical (Qualitative)
Staffing Capacities	Check-in	Flow	Simulation	Quantitative
Check-in Time Relative to Flight	Check-in	Flow	Mathematical Modelling	Quantitative
Number of Check-in Desk	Check-in	Flow	Mathematical Modelling	Unordered Categorical (Qualitative)
Maximum Allowable Queuing-Time	Check-in	Flow	Mathematical Modelling	Quantitative
Layout of Processing/ Queuing	Check-in	Flow	Mathematical Modelling	Qualitative
Dwell Time	Various	Flow	Mathematical Modelling	Quantitative
Trip Purpose	Various	Characteristics	Simulation	Unordered Categorical (Qualitative)
Flight Delays	Departure Gate	Flow	Simulation	Quantitative
Common-use of Check-in?	Check-in	Flow Assumption	Simulation	Binary - Quantitative
Breakdown?	Various	Flow Assumption	Simulation	Binary - Quantitative
Experience (Level) of Operatives	Various	Flow	Simulation	Ordinal - Ordered Categorical (Qualitative)
Interval Between Flights	Various	Flow	Simulation	Quantitative

Table 3-2 Variables Identified as Potentially Useful in this Research

Variable	Clarification
Aircraft Type	related to capacity of 'souls on board'
Annual Departures	with annual periodic peaks *n.b. not measured in this research*
Assigned Check-in Time	determined by the Airport Authority as being sufficient for all passengers to complete the entire departure process
Assigned Flight No.	used as unique identifier when combined with date and time
Baggage Problems	passengers – miscellaneous problems
Breakdown?	of processing station resources
Capacity of Service Facilities	between processing stations – taken to be infinite for practical purposes in this case
Charter or Scheduled [Flight]	Flight
Choice of Supplementary Facilities	Intermediate Holding Areas
Check-in Time Relative to Flight	period before scheduled departure time
Daily Traffic Flow Distribution	with daily peaks
Destination Characteristics	predominant
Domestic or International	passengers
Dwell Time	at processing station
Earliness Distribution	of passenger arrivals at check-in
Experience of Operatives	divided into three levels – 1:trainee 2:competent 3:experienced
Flight Delays	period between scheduled and actual departure
Flight Schedule	of planned departure (and arrival) times
Foreigner/Local	passengers
Has Bags?	passengers divided into no-baggage, hand-baggage only and hold-baggage
Interval Between Flights	of scheduled departures
Late Arrival?	of passengers at check-in or departure
Layout of Processing/ Queuing Facilities	physical layout of airport facilities including temporary barriers especially for queues
Load Factor %	of aircraft
Monthly Departures	with monthly periodic peaks
Number of Check-in Desks	fixed in facility and/or brought into operation
Number of Processing Stations	fixed in facility and/or brought into operation
Passenger Class	Economy; Business-Class or First-Class
Passenger Group Size	number of people in a self-determined group
Percent Pre-ticketed	passengers
Queue Length Check-in	as determinant of queue chosen by passengers
Service Rate	at processing station
Shared/ Dedicated Counter	to airline
Shared/ Dedicated Counter	to specific flight
Staffing Capacities	number of persons normally needed to operate processing station
Sufficient Time for Process?	projected versus actual time to process
Time of Day	relating to daily periodic peaks
Total Passengers per Flight	number of passengers
Transit Passenger?	whether passenger is originating at airport or arriving with another flight to travel onwards
Use of Boarding Gate ONLY?	by certain passengers
Waiting Time	passengers before processing stations
Weekly Departures	relating to weekly periodic peaks

3.6 Flow of Passenger in the Departure Process

There is some dissimilarity in passenger departure flow when compared with manufacturing systems in which 'Lean' originated. The most fundamental difference occurs when a passenger leaves a processing station and control generally reverts to the individual rather than the process. Only when passengers are called to the departure gate in response to the actual time of departure does control pass to the airline. Otherwise, passengers are free to move around intermediate buffer zones which contain commercial concessionary areas, and indeed are encouraged to do so to improve the commercial viability of many airports. This was first seen during the switch of airports from mere transport terminals to a broader framework of economic change and commercial opportunity created by declining aeronautical revenues (Freathy and O'connell 1999). Such concessionary areas have become part leisure attractions and part primary destinations in their own right in response to changing patterns of consumer behaviour (Freathy 2004).

The fixed environment of an airport aims to produce particular flow patterns, whether they proceed through walking or other more automated means of transport such as escalators and beltways. In this sense, an airport superficially resembles a manufacturing operation to which Lean philosophies may be applied. In a manufacturing environment layout governs the appearance and determines the way in which transformed resources, components, information and customers flow through the operation. In an airport, flows are manipulated by airport authorities as well as other national and security authorities using passports and international boarding passes for regulating flow. Airports themselves will guide passengers through a carefully designed network of airports signs, some static and some dynamic (Kellerman 2008).

The ultimate aim is to process passengers at processing stations as quickly as possible and maintain them in commercial areas for the maximum time allowed by the passenger departure process (Kellerman 2008).

3.6.1 Different Types of Buffers

Manufacturing buffers are used to compensate for the variation during the production process including changes due to supply and demand variations. The purpose of a buffer is to protect a schedule by ensuring that components, or in this case passengers, will be where they are needed at the time when needed (Schragenheim and Ronen 1991). Slack et al (2010) calls this 'safety inventory'.

Generally in the passenger departure process, buffers consist of areas which contain in manufacturing terminology 'work-in-progress', 'decoupling inventory' and 'finished goods inventory'.

'Work-in-progress' (WIP) buffers accommodate passengers immediately in front of a processing station or group of processing stations who are waiting to be processed. American terminology uses the term 'waiting in line' for WIP [customers] in service provision (Slack, *et al.* 2010).

There are many disadvantages to service customer waiting in line. Customers often perceive the service they receive as 'queuing facilities they would rather pass through quickly'.

Often, information systems mitigate the effects of queuing. If for example, passengers are informed they will wait 20 minutes in a queue and actually wait for 10 minutes, passengers' perceptions of the queuing experience will be more favourable than if the opposite were true. Slack *et al* (2010) note that London-based, Madame Tussaud's carried out extensive investigations of queuing and reached the following conclusions:

- "time spent idle is perceived as longer than time spent occupied;
- the wait before a service starts is perceived as more tedious than a wait within the service process;
- anxiety or uncertainty heightens the perception that time spent waiting is long;
- a wait of unknown duration is perceived as more tedious than await whose duration is known;
- an unexplained weight is perceived as more tedious than await that is explained;
- the higher the value of the service for the customer, the longer the wait will be tolerated; and
- waiting on one's own is more tedious than waiting in a group (Slack et al, 2010).

While none of these conclusions is strictly concerned with Lean measures, in this research argues that each such customer perception constitutes 'waste'. Thus addressing their concerns becomes part of the Lean improvement process.

'Decoupling inventory' is used when components move between specialised areas in manufacturing. In airports, the decoupling buffer consists of concessionary areas or transit routes where passengers move intermittently between processing stations. As in manufacturing, a decoupling buffer creates the opportunity for independent consideration of scheduling in processing stations and their permitting different speeds of operation (Slack et al, 2010). Positioning a decoupling buffer between processing stations will act as a shock absorber for processing irregularities and for those unforeseen external events which cause delays. It has two advantages. Less coordination is needed to keep the system running smoothly during almost whichever events occur. The second, previously discussed reason is to provide commercial opportunities and revenue for concessionaries and the Airport Authority.

Strictly, the only finished goods buffer is in the passenger departure process beyond the departure gate where passengers wait to board the aircraft.

3.7 Problem-Solving in Passenger Departure Flow

3.7.1 Problem-Solving in Passenger Departure Flow

Problem-solving is one of the most critical aspects of any organization including airports which, when used properly, can reduce costs, increase productivity and customer value (Marksberry, et al. 2011). Problem-solving is an essential feature of the Lean paradigm and is used to achieve the process of continuous improvement (Khalil, et al. 2010).

Problems occur throughout organizations including airports. Before seeking solutions in airport operations, it is important to understand the nature of 'a problem' which Andersen and Fagerhaug (2006) define as:

1. A state of difficulty that needs to be resolved; or
2. A question proposed for solution.

In other words, a problem is "any situation which is perceived to exist between what is and what should be" (Khalil, *et al.* 2010).

Andersen and Fagerhaug (2006) note that two important characteristics define 'a problem':

1. The problem is a given state of affairs plagued with some difficulty or undesired status; and
2. A problem represents a challenge that encourages solving to establish more desirable circumstances.

One of the main challenges for any Airport Authority is to cope with and solve passenger departure flow issues to facilitate managing the airport passenger efficiently and effectively. Passenger departure flow is an essential process in airport facilitates, to service and to aircraft departure time. Several issues are identified and explored in the literature. Included among them are:

1. Congestion in Queuing Areas

   Congestion in airport processes including those before security or check-in is an issue that needs dealing with effectively to facilitate passenger flow through the process (Solak, et al. 2009).
2. The Skills and Efficiency of Staff

   As an example, the departure process requires security staff to interact with passengers and security technology. Kaffa-Jackou, *et al.*(2009) argue the efficiency and skills of security staff is a major issue for all airport authorities. Similar interactions take place elsewhere in the departure process such as at check-in. All such interactions need suitable staff competences, including social, cultural and communication skills to deal with passengers.
3. Security

   Security-related issues such as identity and materials carried, including those which affect the airport terminal security or subsequent flight security have been identified as issues of crucial importance which have to be addressed during the passenger departure process (passenger departure process) (Bittel, *et al.* 2007, Kaffa-Jackou, *et al.* 2009).

4. Passengers Comfort

   Passenger comfort during the passenger departure process, especially when queuing at processing stations is a key element of passenger satisfaction (Kaffa-Jackou, *et al.* 2009).

5. Rate of Passenger Arrival at the Airport

   Arrival rate whether at the airport or at processing stations presents multiple challenges. Related factors include departure time, flight scheduling and type of flight (Christauskas and Stanaitis 2008, Gilliam 1979). Arrival rate is a function of time with, for example, peak passengers arriving at the check-in counter during the middle part of the check-in opening period (Van Dijk and Van Der Sluis 2006).

6. Delays at Processing Stations

   Delays occurs at all processing stations. For example, queuing-time at the check-in station is an important early determiner of satisfaction criteria and a significant problem during passenger departure flow (Rauch and Kljajić 2006). Queuing-time during check-in depends on several factors. These include flight departure time, passengers' dynamic arrival pattern, available capacity, and self-service or remote check-in facilities. In another area, ticket screening also depends on several factors such as some countries requiring further visa and security checks (Chang and Yang 2008, Ching-Hui 2010, Van Dijk and Van Der Sluis 2006).

While each of the six issues above are important not all may be directly addressed by the research though each will be borne in mind when determining improvement strategies in an effort to improve these issues also. The main focus of the problem to be addressed remains as (6) 'Delays at processing stations' including the ways passenger flow may be improved in queues immediately before processing stations and how short of processing time may be achieved.

3.7.2 The Problem-Solving Framework

Researchers have often examined the process and practice of problem-solving, especially when they involve team processes. Team processes are common in most of the elements found in the departure process such as security (Kaffa-Jackou, et al. 2009), check-in or passport and boarding card verification. Harley (1995), for example, suggested that problem-solving required a 'letting go' of negative mind states and a carefully constructed framework consisting of eleven steps mainly consisting of alternative identification and agreement by team members. The first step needs team members to put aside their individual perspectives and see the team as an instrument of problem-solving:

Cervone (2006) also advocates an 11 point problem-solving framework though different from Harley's above. Cervone's eleven point framework is as shows figure 3-1 below:

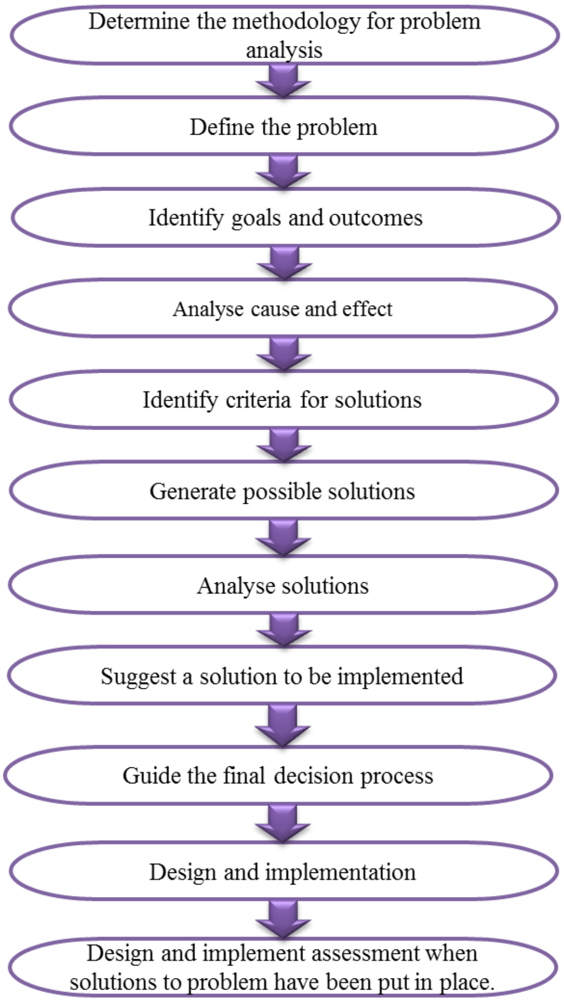

Figure 3-1 Cervone's eleven point framework

However, Cervone (2006) notes that if teams employ such a problem-solving methodology too rigidly, they may see it as being long and tedious. Instead, Cervone (2006) suggests the steps should be integrated as a natural part of an organization's development efforts involving all affected parties. Even in well-integrated teams different people value different paths or outcomes. Only by explicitly stating the criteria that will define ‘success’ at an early stage, can a team stay focussed and know what is expected of them in the context of the total departure process.

Another alternative is to use a Markov Decision Problem framework which exclusively uses a mathematical approach (Cheng-Lung and Caves 2004, Meirina, et al. 2008, Peterson and Bertsimas 1995). Strictly, Markov Decision Processes (MDPs) are defined as discrete-time stochastic control processes rather than problem-solving processes which examine the whole system. MDPs are likely to of greatest value only where outcomes are partly under the control of decision-makers in the process, and partly random. Arguably in an airport context, the most random element is aircraft arrival times. These may affect departure times and thus, determines how passengers are pulled through the system. From this project’s perspective MD frameworks are the least practical solution because the departure process is normally broadly under control.

Alternate formal problem-solving methods are used within knowledge based systems to define patterns of behaviour (Fensel and Motta 2001). They have been the subject of wide-ranging research in certain engineering applications but are intensely mathematical in the approach. Consequently, they remain unsuitable for process managers who generally do not have the advanced mathematical capabilities required. Nor can they be translated in understandable form for teams controlling various elements of departure processes.

3.7.3 The Problem-Solving Model

Different organizations use different models of problem-solving. There are three main types defined by the people who draft them (Khurana 1999):

1. Technical specialists/ quality staff/managers are the main architect of problem-solving;
2. Managers wholly delegate the process of problem-solving to team members;
3. Both managers and team members collectively solve problems.

The problem with the first model is it over-emphasises the importance of managers and leads to rule-based systems with team members rarely solving problems themselves (Khurana 1999). In the second model, team members became highly motivated, though managers are increasingly seen as being detached from the problem. Further problems occur when team members lack the skills and technical knowledge to tackle the root cause of many process problems. The third model had the advantage of bringing together different strengths to the problem-solving effort, both technical and practical and provides the best solutions.

In airport operations, conditions are often imposed by external agencies, especially those relating to security and passenger safety. Practical skills alone cannot address all of the problems involved and make the "hard choices" involved (Bittel, et al. 2007) including introducing out-of-airport measures such as passenger pre-screening (Majeske and Lauer 2011). For the security element of the process, problems abound comprising needs to increase regulations and costs resulting in time-delays and greater inconvenience (Kaffa-Jackou, et al. 2009). Such problems have frequently resulted in congestion and bottlenecks which directly affect airport terminal capacity and service planning (Solak, et al. 2009). This suggests the third of Khurana's (1999) models is the one preferred. Otherwise, if not chosen, misunderstandings of how to develop practical solutions may develop (Cervone 2006). Often workgroups have less clear understanding of total costs involved and frequently believe that apparently 'cheap' solutions are the most effective. To overcome this, management involvement is vital to provide detailed information to the team so they can understand the practical limits of any solutions which may be considered for implementation.

3.8 Chapter Summary

This Chapter has examined the nature and formal approaches towards problem-solving in an airport departure environment. It focuses on identifying airport passenger flow and related issues in existing departure models in the literature. This Chapter identified existing models of passenger departure flow and models of control and examine the special features of queuing within the departure process. The Chapter further examined the types of flow and elements such as the effects of passenger group size, passenger class and similar issues. Some sixty-two different variables were identified in the literature and those variables most useful in this research were isolated. Additionally, different types of buffers within the system were also examined. Finally, this Chapter examined problem-solving in passenger departure flow and described in detail the problem-solving framework.

Chapter 4 : Research Methodology

4.1 Overview

This Chapter gives a brief introduction to research questions, research philosophy and their relationship to the aims and objectives of the research. It provides a detailed explanation of why certain data were collected. This Chapter also illustrates the relevance of selected research strategy and research steps to the research questions and objectives, how the methods used fulfilled the ethical requirements for the single case study which was the subject of this research and exemplifies the proposed research methodology.

4.2 Research Questions and Objectives

Developing research questions is one of the most important first steps in developing a research project (Saunders, et al. 2007). Saunders et al (2007) suggest "*the importance of this cannot be overemphasised*" as one of the key criteria of future research success and the foundation of the research project. The research questions (Table 4-1) were developed to show a clear set of conclusions could be drawn from empirical field data. Developing these seven questions followed a step-by-step approach with each research questions leading directly to research objectives. This relationship is shown in Table 4-1 overleaf.

Table 4-1 Research Questions

	Research Questions	Research Objectives-Explanation
1.	What is the precise configuration of processes involved in the passenger departure process?	1. To examine and evaluate: a. The overall passenger departure process in Terminal 3 of Abu Dhabi Airport; b. Each of the discrete groups of processing stations involved in the process; c. The various routes taken through the process by each type and class of passenger, including transit.
2.	What are the needs of the various parties involved in the process?	2 To examine and evaluate a. The needs of the various parties to the process: i.e. Check-in, emigration and security b. Any limiting legal and operational constraints which might affect the passenger departure process.
3.	What steps are involved in each discrete group of processing stations?	3. To examine, measure and evaluate in detail the present operations at the different stages of departure process.
4.	What variations are involved that affect each group of processing stations?	4. To examine, measure and evaluate each of the variations that may affect the passenger departure process both generally and for each type and class of passenger.
5.	How might each discrete group of processing stations be optimised using Lean philosophies and DES?	5. To develop a DES model representing the departure process and optimise the model by taking into account various conditions likely to be found in each of the processes i.e. variability.
6.	What are the intermediate steps between each group of processing stations belongs to different stages of departure process?	6. To examine and evaluate the various intermediate holding areas and facilities for passengers.
7.	What signals are involved pulling passengers to the next group of processing station stations within the process?	7. To examine and evaluate the effectiveness of current systems of signalling passengers to move to various stages of the process

4.3 Research Philosophy, Approach and Strategy

4.3.1 Research Philosophy

The twin research philosophies adopted were concerned with developing knowledge in the particular field of study involving passenger departure in Abu Dhabi Airport. Developing research philosophies was a fundamental step towards understanding how this research had necessarily to progress (Bryman 2008, Saunders, et al. 2007). They reflected important assumptions made by this researcher about the way he viewed the world, influenced both by practical considerations and epistemology; as to what constitutes acceptable knowledge in this field of study and ontology; and the nature of reality (Saunders, et al. 2007). Epistemologically, in this research carefully considered ‘positivist’, ‘realist’ and ‘interpretivist stances’ described by Saunders *et al* (2007) and the researcher decided to adopt a partly positivist, partly realist research philosophy (Table 4-2).

Table 4-2 Epistemological Considerations

Type of Philosophy	Description	Commentary	Decision
Positivist	When a researcher takes the philosophical stance of a natural scientist and work with observable data.	Has advantages but depends on the research strategy. In this case, the need for specific empirical data suggested this approach was adopted though not as the only approach.	Partially adopted
Realist	The essence of realism is that what the senses show to be true is the reality. This philosophy lies behind a scientific approach to research.	A realist philosophy enabled this researcher to separate sociological effects from empirical effects seen in experimentation and simulation.	Partially adopted
Interpretivist	This focussed on social interactions between various actors in any process being researched.	Social interactions are not the principal reason behind the research and conflict with the aim to use Lean philosophies and methods.	Rejected

In ontological terms, the researcher considered project both objectivist and subjectivist stances (Saunders et al 2007) and decided an objectivist approach was more suitable because of overwhelming influence of external factors which affected Terminal 3’s environment (Table 4-3).

Table 4-3 Ontological Considerations

Type of Philosophy	Description	Commentary	Decision
Objectivist	Used where the research subject is affected by forces external to the process.	With a strong regulatory background to all airport operations, together with the overriding operational needs of the various actors, the way processes are arranged are strongly affected by external forces which cannot be ignored.	Adopted
Subjectivist	Used where the research subject is greatly affected by the perceptions and subsequent actions of the actors involved.	Although internal management by the internal parties, the main influence over the passenger departure process is external forces.	Rejected

Taking both epistemology and ontology into account suggested a 'functionalist' research paradigm (Burrell and Morgan 1979) be adopted. This paradigm assumes that 'objectivist' and 'regulatory' dimensions were adopted. This paradigm was concerned with developing a series of rational explanations for why a particular organizational problem is occurring and how it could be solved within the current structure of regulation covering the involved organizations' operations in Abu Dhabi Airport. As Burrell and Morgan (1979) note "*it is often problem oriented in approach, concerned to provide practical solutions to practical problems.*"

Nevertheless, as Saunders *et al* (2007) note, the research philosophy was not made up of hard and fast rules but rather guides the main stance towards any research project. In this case, practical reality meant more than one philosophy may be employed secondary to the main research philosophy, which according to Saunders et al (2007) is an approach often taken by other researchers.

4.3.2 Research Approach

Developing a research approach is more straightforward, though again, there are no right and wrong approaches. The principal choice is between a deductive and an inductive approach towards theory (Saunders et al 2007) (Table 4-4).

Table 4-4 Research Approach

Type of Approach	Description	Commentary	Decision
Deductive	Uses scientific methods of research built on existing theories.	In this case, the aim is to show whether Lean philosophies and methods are capable of improving the passenger departure process as a whole and that of individual processing stations.	Adopted
Inductive	Assumes a new theory will be developed.	The research is not searching for a new theory but rather to show how Lean methods can be used to improve the processes.	Rejected

Saunders *et al* (2007, p.117) observe that deduction works best when adopting the five-stage approach developed by Robson (2002) as follows:

1. *"Deducing hypotheses from Lean principles;*
2. *Expressing the hypotheses in operational terms;*
3. *Testing the operational hypothesis;*
4. *Examining specific outcomes of the enquiry whether from empirical information or simulation studies; and*
5. *If necessary modifying the theory after considering the findings."*

In this research, the hypothesis was straightforward:

> **H1**: Applying Lean principles and tools to the whole passenger departure process as defined in Section 2.4.1 of Chapter 2 will result in a measurable performance improvement.

Chapter 3 expanded on this hypothesis and examined how the second stage was developed. This Chapter describes how the third stage; 'testing the operational hypothesis' was accomplished.

4.3.3 Research Strategy

Table 4-5 Section of the Research Strategy

Type of Approach	Description	Commentary	Decision
Survey	Normally associated with a deductive approach, surveys are normally used for exploratory and descriptive research.	Unlikely to yield any significant information relevant to the research subject.	Rejected
Action Research	Involves fact-finding and evaluation. The researcher takes actual part in operations being studied. Action research emphasises the iterative nature of the process of diagnosing, planning, taking action and evaluating.	This project is too wide in scope and so it is impractical for this researcher to become directly involved in this type of research. In any case, the various actors would not allow the system is to be interfered in 'live' operations.	Rejected
Ethnography	Deeply rooted in the inductive approach, ethnography emanates from the field of anthropology and seeks to explain the social world the research subjects inhabit.	An inductive approach was rejected earlier. This project is not concerned with social interactions but instead with the processes involved and their flow.	Rejected
Archival Research	Makes use of administrative records and documents of the parties involved as the principal source of data. Should not be confused with secondary data analysis. This type of research focusses on the past and changes over time.	Archival research alone was considered extremely unlikely to be able to produce the required results relative to the aims (Section 1.4) of the project.	Rejected
Grounded Theory	An inductive approach towards theory-building. Theory is developed from data generated by a series of observations.	The inductive approach was rejected earlier, Table 4-4.	Rejected
Case Study	A strategy for doing research which involves an empirical investigation of a particular phenomenon within its real life context.	Using a case study approach involving Abu Dhabi Airport T3 did not adversely affect either the chosen research philosophy or approach.	Adopted

Type of Approach (cont'd)	Description	Commentary	Decision
Experiment	Classical form of research which is able to study causal links and whether the change in one or more interdependent variables produces a change in another dependent variable.	Simulation using Simul8 provided a practical way for experimenting with the total process and individual processing stations where the existing arrangement could be readily compared with any proposed changes without interfering with operations in progress.	Adopted

Saunders *et al* (2007) observe there is a positive need for a clear research strategy and propose various alternatives. These are set out in Table 4-5 together with a commentary on each strategic method applied to this research. In this case, the funding organization made some type of study on Abu Dhabi Airport a condition for support. This research used Terminal 3 as a case study. However, having already logically decided to adopt a 'realist and positivist' *functionalist* philosophy, the experimental strategy fitted well, but provided only some of the answers. Consequently the strategy then demanded to know if a quantitative or qualitative data method was used and if both, in what proportion.

4.3.3.1 Quantitative or Qualitative Methods?

Quantitative research has been the dominant paradigm for conducting social research, though since the 1970s, qualitative research has been used increasingly (Bryman 2008). A step-by-step approach was taken to deciding which was the most suitable.

Qualitative research:

1. Mainly emphasises an inductive approach to the relationship between theory and research and the qualitative approach leads to mainly generation of theories;
2. Rejects the practices and norms of natural scientific approach and prefers to emphasise the way individuals interpret their social world;
3. Embodies a view that social reality is constantly shifting that emerges from an individual's feelings.

In this case, however qualitative served another function; to triangulate quantitative findings. This is discussed in more detail later in this Chapter.

Quantitative research refers to the collection and analysis of data which are essentially numeric in character. This means mathematical operations can be conducted on these data or used as a basis for simulation. Such analysis ranges from creating simple tables or diagrams to show frequencies and using statistical methods to enable comparisons by establishing numerical relationships between variables (Saunders, et al. 2007).Using a quantitative research strategy:

1. Entails a deductive approach to the relationship between theory and research. Emphasis is placed on testing theories;
2. Normally quantitative researchers use the practices of the natural scientific model, especially positivism;
3. Researchers use social reality as an external objectives reality.

The distinction between the two methods is shown in Table 4-6.

Table 4-6 Quantitative Versus Qualitative Research
source: Bryman (2008)

Quantitative Research	Qualitative Research
Numbers	Words
Point of view of researcher	Point of view of participants
Researcher distinct	Researcher close
Theory testing	Theory emergent
Static	Process
Structured	Unstructured
Generalisation	Contextual understanding
Hard, reliable data	Rich, deep data
Macro	Micro
Behaviour	Meaning
Artificial settings	Natural settings

Many researchers believe the epistemological foundations of both methods differ. Consequently, Bryman (2008) observes there are distinct differences both with regard to the collection and analysis of data. In this case, quantitative data provided the main source of information on which simulations are based. Simulations then output additional quantitative data for further analysis. The collection of quantitative data and subsequent experimental findings were verified by qualitative data obtained during unstructured dialogue with process managers and airport executives.

As well as differences between the two research strategies, there are also similarities. Bryman (2008) lists these as follows. He suggests that both are concerned with:

1. Data reduction;
2. Answering research questions;
3. Relating data analysis to the research literature;
4. Variation;
5. Treating frequency as a springboard for analysis;
6. Ensuring deliberate distortion does not occur;
7. The question of error;
8. Ensuring research methods are appropriate to research questions.

By using the special properties of each method as well as their similarities, the researcher did not have to decide definitively between qualitative or quantitative methods. Instead he used mixed-methods research (Bryman 2008, Saunders, *et al.* 2007). Bryman (2008) observes that mixed-methods are not only entirely compatible, but both are feasible and desirable when combined.

Various authors have proposed different methods for combining qualitative and quantitative research. Hammersley (1996) proposes three alternative approaches to mixed-methods research:

1. Triangulation: where the researcher uses qualitative research to verify quantitative research findings;
2. Facilitation: where either a quantitative or qualitative research method is used to aid the use of the other method;
3. Complementarily: where the two research strategies are used to explore different aspects of the investigation to ensure both are valid.

This research mainly relied on quantitative methods, although as noted earlier a process of verification was also needed as simple measurement alone could not throw sufficient light on external influences on airport operations. This called for 'triangulation' to be used.

4.3.3.2 Triangulation Methodology

In context of this research, triangulation refers to the use of different data collection techniques within a research study to ensure that collected data is a true indicator of the conditions which exist within the research scenario (Bryman 2008, Saunders, *et al.* 2007). Only when external influences were understood could experimental methods and conclusions be carefully checked to ensure that quantitative data and research findings remain within the possible.

Triangulation ensures greater validity of the results because it provides a system of mutual collaboration of results. Nevertheless, as Bryman (2008) notes, to be strictly termed triangulation a formal method of coding of qualitative results should take place. In this research it did not. Instead, this researcher approached it more informally because of the number of different parties involved in the departure process and other issues described earlier (Sections 2.5.1, 2.7, 3.3.1). Instead, a process of what Bryman (2008) describes as "unplanned triangulation" took place because issues arose from analysis which could not initially be fully explained without taking seeking further explanations from process managers and airport executives. While the approach combined both quantitative and qualitative methods in mixed-methods research, formal triangulation which involved the codified analysis of responses could not take place. Nevertheless, objectives of mutual reinforcement of results were met by cross referencing verbal discussions from varied sources.

Current research has approached the method by cultivating strong personal relationships across the airport so that anecdotal evidence arising from unstructured questioning could be used to verify methods of information collection, the accuracy of data and numeric information collected, and the likely validity of results. This mirrors the approach described for social scientists and investigative journals where if several people are asked for comments focussed on specific circumstances and instances, especially if they come from various sources results from quantitative methods may be taken as accurate. In this case, researcher developed relationships which enabled different teams, disciplines or sections to be questioned separately and at different points in time. Only when results of mixed-methods which involved rich questioning and quantitative results uncovered no apparent discrepancies, were they accepted. Collection of data is discussed in greater detail in the following Chapter.

4.4 Validity and Reliability of Data

Reliability and validity of data lie at the heart of credible research findings. This project used these concepts to ensure the project was repeatable and robust rather than simply seeking to find information which confirmed the hypothesis (Section 4.3.2) (Saunders, *et al.* 2007)

4.4.1 Validity

Validity refers to the accuracy by which research is conducted and how appropriate methods used are in conducting the research (Maylor and Blackmon 2005). In this case the objectives was to measure various process and waiting times for each of the separate workstations and then using triangulation methods described in above to ensure the correct methods used meet the aims and objectives of the research and that these methods were not, in fact, recording data or information of the wrong type

Saunders et al (2007, p.150) define validity as:

1. "*the extent to which data collection methods accurately measure what they were intended to measure;*
2. *the extent to which research findings are really about what they profess to be about".*

This researcher paid special attention to internal validity; the extent to which findings can be attributed to interventions rather than flaws in the research design, as well as to generalizability.

Generalizability (also known as external validity), is where data collected is peculiar one setting or whether it can be applied to similar settings elsewhere. This researcher was concerned to establish whether Abu Dhabi Airport and the parties operating within it is typical of other airports, or is markedly different in some way (Saunders *et al* 2007).

Saunders et al (2007) observe that one must ensure data is valid when seeking cause-and-effect relationships. In this case steps were taken to avoid threats to validity posed by:

1. History, where recent or past special events in the airport had the potential to bias results.
2. Testing, where those observed, especially operatives in processing stations make special efforts to create abnormal results in case normal results prejudice their position.
3. Instrumentation, where management instructions to take specific related actions in waiting lines or processing stations create abnormal results data.
4. Ambiguity about causal direction which occurs when the direction of the cause-and-effect relationships is not properly understood. In other words, is what appears to be the outcome is caused by particular behaviours or actions, or are the particular behaviours being modified by participant-observed outcomes? Queue switching by passengers is an example of this where it is unclear whether service times or operator-related factors are causing passengers to switch, or operator-observed queue switching causes operators to behave differently.
5. Logic leaps and false assumptions if the collection of data is not as a result of a properly designed and conducted method of collection.
6. Improper identification of the research population, that is to say are the results for the measurement of flow in one particular passenger class wholly applicable only to that class or are the actions of passengers in another class interfering with the results;
7. Data collection errors, Data interpretation errors and Developing conclusions from the data in a robust and repeatable way.

In this case, careful triangulation was used as the principal method of overcoming validity errors. Asking various parties (except passengers), whether participants or nonparticipants in the process or processing station under observation disclosed any potential errors in observation which could then be overcome.

4.4.2 Reliability

Reliability of measurement is that which, if another researcher undertook the same research in the same circumstances, they would be able to collect the same data (Maylor and Blackmon 2005).

Saunders et al (2007, p149) describe 'reliability' as:

> *"the extent to which data collection techniques will yield consistent findings, similar observations and conclusions reached by other researchers or if there is transparency in how sense was made from the raw data"*

This was divided into two subsets:

1. ***Measurement reliability***: suitability of data was compared to research aims and objectives with particular attention being paid to field measurement validity and coverage. Coverage ensured that every possible measures necessary for the project was taken. Attention was also given to those measurements which were *not* taken to ensure they were correctly and deliberately omitted.
2. ***Secondary source reliability***: the use of secondary sources of data for analysis took into account the need to meet research aims. Special attention was paid to methods other researchers used to ensure validity and reliability and how they excluded measurement bias.

Saunders, et al (2007) listed the three aims of creating reliability in data measurement:

1. The measure is repeatable by being able to gather the same data on other occasions. In this case, 'the same data' should not be confused with 'the same results', because of inherent variability of individual passengers' or operatives' actions during the departure process.
2. Similar observations would be made by other researchers using the same methods; and
3. Transparency is achieved when processing the raw data.

The three aims above are achieved by overcoming the following threats to reliability.

4. Subject or participant error when those participating in the research return inherently different results depending when the results were taken.

5. Subject or participant bias where interviewees may simply say what their managers expect them to say.
6. Observer error where the researcher taking data used significant variations in methods of obtaining or recording data.
7. Observer bias when data collected received treatment which would ensure it found pre-envisaged results.

The ACI which regularly measures quality in all airports worldwide have produced a detailed Airports Service Quality Performance (ASQP) (Appendix B1) methodology accompanied by a survey manual which airport staff are accustomed to seeing regularly applied. ASQP methodology was used, both for observer consistency and to overcome participant error or bias. The methodology was evaluated in detail by this researcher in advance of its use to ensure that it could produce the correct data to meet the precise aims and objectives of this research.

4.5 Simulating the Departure Process.

Simulation is defined as "*the imitation of the operation of a real-world process or system over time*" (Banks 1999: p.7) and is used to ask 'what if' questions about the real process and helps to design improvements to it. An important objective for simulating the passenger departure process was to reduce WIP in the form of waiting or queuing passengers to free them to carry out discretionary activity and enjoy the airport's other facilities.

A computer simulation is built as a series of building blocks (Disney, *et al.* 1997), especially in the case of (groups of) processing stations. Normally, in a manufacturing context one would consider processing time, queuing-time, reject and rework levels, and inventory holdings. In the departure process this translates into the time it takes for a processing station to deal with an individual passenger, the number of passengers and the time spent waiting in queues. 'Reject' would be when a passenger is stopped at any point during the departure process from proceeding to board the aircraft and continuing their journey. 'Rework' is where passengers are required to take part in another process. For example, when checking-in, baggage may be overweight and so a passenger is redirected to the excess baggage charging area before being allowed to re-join the check-in queue. In some cases, rework is mandatory by law. A certain percentage of passengers passing through security are required under international law to be subjected to additional security checks before being able to exit the security gate (Sita 2008).

Previous researchers such as Jim and Chang (1998), Van Dijk& Van Der Sluis (2006) and Ching-Hui (2010) have used simulation to improve various elements of the passenger departure process. For the entire departure process, this involves many complex activities including data collection, model building, simulation, generating alternatives, analysing outputs, and presenting results (Jim and Chang 1998). This enables formulating and implementing recommendations based on these results. It is not normally possible to emulate, this using 'real-world' processes as they would create too much disruption within the airport.

4.5.1 The Role of Simulation in a Lean Departure Process

DES can model process of various types and complexities where events happen at discrete times (Khade and Metlen 2011) and the time between events and processing stations is stochastic. One may define an event as "*anything the changes attributes and/or variables related to a [service], an/or statistics of a process*" (Khade and Metlen 2011). Variability in this sense may be defined in two ways, dysfunctional variability and strategic variability (Suri 1998). Dysfunctional variability is caused by errors and poor systems such as constantly changing priorities and 'lumpy' demand. Strategic variability is deliberately introduced by an organization to maintain its competitiveness. This may occur, for example, when there is highly unpredictable demand, a large variety of passenger options or the offer of customised services. Suri (1998) suggests the focus should be on dysfunctional variability. There are significant advantages in using DES which Khade and Metlen (2011) list as:

1. Improvement to flow;
2. Better resource utilisation;
3. Improved speed through the process;
4. Reduced costs and improved profitability;
5. Changes may be determined within a given confidence level.

Banks (1999, Banks, *et al.* 2010) suggests additional advantages to using DES from the research perspective:

1. Enables the choice of the best solution without committing resources to their acquisition;
2. Allows researchers to compress or expand time to allow a thorough investigation of particular phenomena;
3. Allows managers and researchers to understand why certain phenomena occur in real processes, in a way impossible in operational processes;
4. Allows exploration possibilities which involve new policies, operating procedures or methods without the expense and disruption of experimenting with the process 'on the ground';
5. Enables problem diagnosis and especially understanding of the variables in any complex system;
6. Identifies constraints and bottlenecks and permits analysis of their effects.

Other advantages involve helping managers visualise proposals for change to the process and build consensus among operatives in advance of changes on the ground.

Using simulation allowed this research to show progressively how the passenger departure process can control and reduce costs, increase flow and velocity while at the same time improving quality of service at each of the processing stations (Khade and Metlen 2011).

4.6 Research Method Steps

Figure 4.1 overleaf shows the research methods steps adopted in this research.

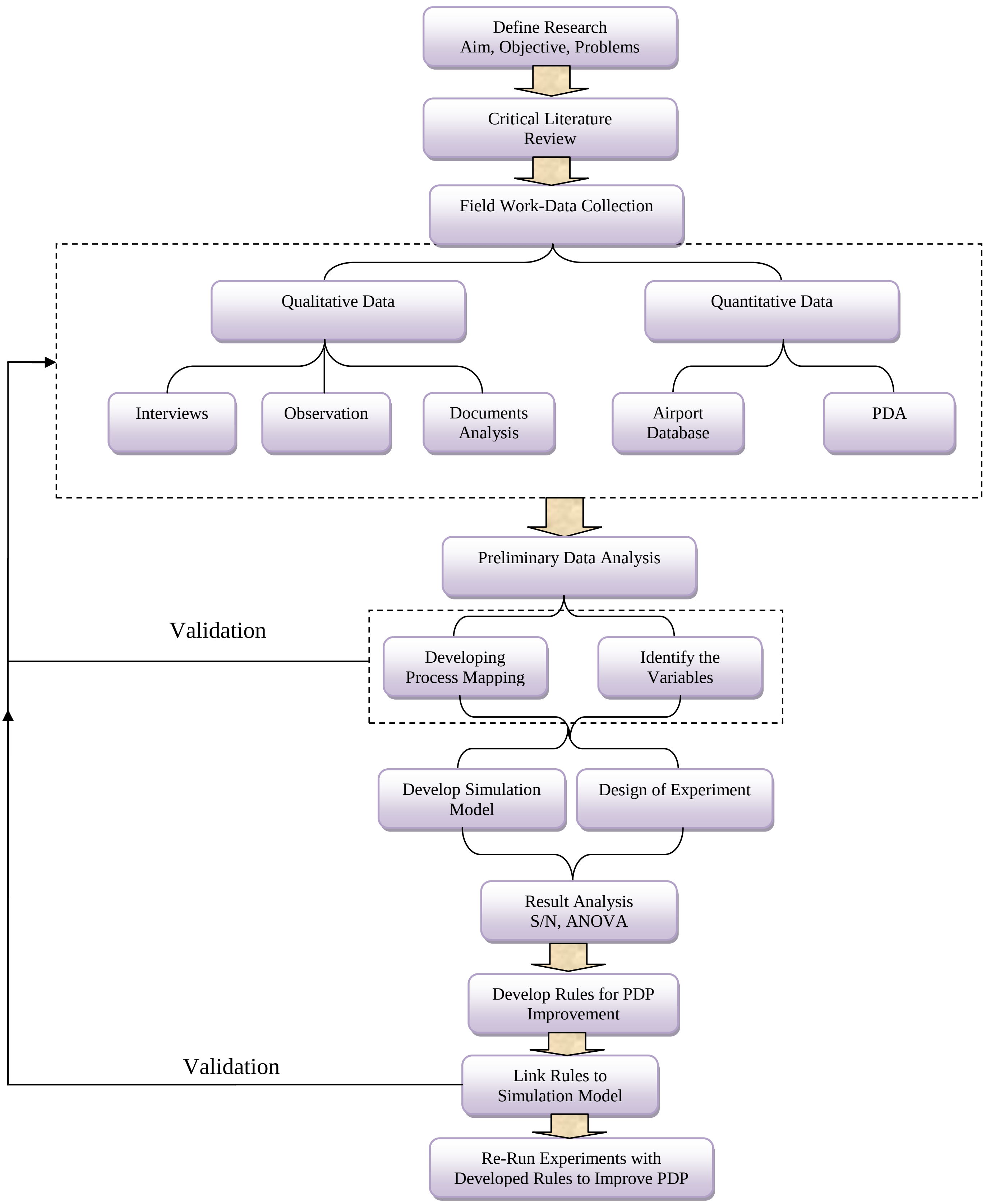

Figure 4-1 Research Methodology

Step 1: Define Research Aim, Objective, and Problems

This step focused on clarifying the research aim and objectives and elaborates the justification of carrying the research. The step is also elaborating the research problem, as illustrated in sections (1.4 and 1.5).

Step 2: Critical Literature Review

Critical literature review is done to develop understanding and knowledge about the research project domain and to gain the awareness of other research (on-going/completed) in the chose research problem.

Step 3: Field Work-Data Collection

Using research methods influenced by the research philosophy, approach and strategy, this researcher adopted a mixed-methods research methodology which involved collecting both qualitative and quantitative data and analysis procedures to take quantitative measurements and in a way which will allow numerical data to be questioned in the triangulation process (Saunders et al 2007). This gives greater usefulness to the research because it provides better opportunities to evaluate the extent to which research findings can be trusted and inferences made from them. This step focuses on collecting quantitative and qualitative date to achieve research objectives. This is needed to provide raw data to analyse the current performance of the process and to be used in the simulation the process.

1. Quantitative Data Collection

Quantitative researchers *must* have several special preoccupations (Bryman 2008). These include:

1. Measurement;
2. Causality;
3. Generalisation; and
4. Replication.

Research methods addressed these issues and consist of detailed observations of each process to collect random and process specific data through sampling at each processing station (Do, et al. 2010, Khalil 2005, Roanes-Lozano, et al. 2004) on:

1. Process Times;
2. Numbers of Passengers;
3. Arrival Patterns of Passengers;

These provided sufficient quantity and quality of data to drive the program of DES using Simul8, as well as subsequent data examination and analysis. The following quantitative data collection method used in this research with brief explanation of the main drives for adopting each method adopted:

1. Use of ASQP programme-Personal Digital Assistant (PDA) devices (section 5.2.3)
2. Airport database; to understand the demand and variability from flight schedules, past demand, etc.

PDA used for multiple observations at each processing station of the departure passenger during a 60 minute period in each processing station before moving to the next station of the process. During the 60 minutes setting a series of 10 minutes observations ('observation set') be taken and recorded on the PDA. If an observer arrived at the processing station and no queue was in place, ASQP required the observer to wait five minutes before the next observation (Appendix B2).

In each case, PDA observations started when a passenger presented themselves to the processing station. Around twenty passengers were observed, whether singly or in groups and the 20th passenger from the queue identified. At the expiration of 10 minutes, or when the final or 20th passenger in the observation set was completely processed, recording of the observation set was terminated. (Appendix B1) shows a series of additional rules for recording passenger flow and processing.

No measurements were made of passengers waiting in concessionary areas between processing stations or before the check-in queue. These holding areas were assumed to be infinite for practical purposes.

2. Qualitative Date Collection

Qualitative data is collected in this research to supplement and verify the quantitative data required to simulate the PDP flow. Qualitative data has been collected by face-to-face interviews, observation and documents analysis.

1. Interviews: Conduct unstructured interviews with senior managers from the Airport Authority, airlines and security authorities to determine the problems they faced and to gain a picture of important issues likely to be encountered during the research. This provided greater context to the research. Discuss with the managers of operatives of different processes; taking care to choose multiple managers from each process who dealt with passengers at different times of day, week and month. This established the type of issues that front line operators thought were important to further inform the questioning process. The main drives for interviewing the manger can be summarised in the following:

    a. To get the approval to accuracy out the research in details

    b. To support the research through encouraging stations managers and employees to support the research.
    c. To explain and discuss the terminal 3 passenger flow process
2. Observations: Perform detailed visual inspection of the airport at various times to corroborate discussions with senior managers and operatives and to ascertain any other specific problems which might be envisaged while collecting quantitative data. This includes checking any lean principles that adopted in the airport terminal and the passenger flow. This is needed to help understanding the process and identify any waste or problem in the process.
3. Documents Analysis: this includes analysing airport annual reports performance, flight schedule and activities. This analysis helps in providing data in measuring the trend of the airport performance.

3. Development of Research Instruments

During both stages of collecting quantitative and qualitative data detailed about important factors emerged;

1. Details of the ASQ performance benchmarking program, which mirrored almost exactly the collection of quantitative and qualitative data proposed in this study; and
2. The need for extreme caution in handling these data for security reasons.

In the first case, the ACI, an international governing and quality assurance body for the airport industry developed a programme first launched in 2007 called the ASQP to provide a range of management tools to assist airports improve customer service and processes such as the passenger departure process (Aci 2015). The total programme involves seventeen key performance indicators throughout the airport measured through a series of observations carefully scheduled to ensure an accurate reflection of measurements of processing and passenger flow in airports. Since its launch the ASQP methodology has subsequently been tested in airports worldwide.

Part of the ASQP programme is a suite of specially designed software operating on Personal Digital Assistant (PDA) devices. Details of the format of the software are contained in (Appendix B1).There seemed little point in 'reinventing the wheel' and so relevant parts of the ASQP program were used. The Airport Authority provided a software-enabled PDA to enable data collection. For secure handling of data, the ASQP program was linked directly to a secure computer storage facility heavily shielded from tampering. Adopting the ASQP method and PDA device meant both factors could be addressed at the same time.

Step 4: Preliminary Data Analysis

Qualitative and quantitative date collected from the previous step is used to develop the process mapping and then DES model for PDP flow. Some of the data includes;

1. Identify the activities involved in the PDP process and associated attributes, such as processing times, number of stations, queue size, etc.

2. Daily, weekly and monthly demand to create time distributions for different passenger classes.

Step 5: Developing process mapping and Identify Variables

This step develops the PDP flow of terminal 3 based on current layout and physical resources available. It is important and critical to develop process mapping of the terminal 3 to help simulating the passenger flow. The following describes briefly the approaches adopted in developing process mapping of the economy-class, Figure 5-9. The same approached have been adopted in developing the rest of process mapping developed, Figures 5-3, 5-19. The process mapping is developed based on the following steps;

1. Airport Documents

   The first step in developing economy-class mapping is by reviewing the terminal 3 documents and how designed to serve the terminal passengers. The document review helped to develop initial understanding of the passenger flow from the physical design of the terminal. Once this step has been completed, the researcher carried out personal observation of the economy-class.
2. Observation

   The researcher has made personal observation of passenger flow of the economy-class. This is needed to help understanding and awareness of the passenger flow of the economy-class. The researcher developed an initial draft of the process mapping with personal comments in any parts that needs more explanation and understanding. Once the observation completed the researcher arranged face-to-face meeting with economy-class manager to discuss the class process mapping.
3. Face-to-face interview

   Face to face interviews were carried out with the economy-class manger to discuss and explain the passenger flow in the economy. This is needed due to the experience and knowledge of the manager on the economy line. The interviews were based on unstructured interviews to explore and discuss the passenger flow of the economy-class. The questions of the interview were focused on the passenger flow and activities of each station of the flow. This includes the involvement of the human and physical parts of the process. The main outcome of the interview was an initial sketch of the passenger flow in the economy class.

This step also identifies variables from the literature were shown in Table 3-1 and those most likely to be useful in Table 3-2 in Section 3.5 in the previous chapter. In the event, during the research and having decided on utilising the ASQP methodology (Appendix B1) this determined the factors from Table 3-2 which were most useful for measurement purposes. ASQP also informed which Key Performance Indicators were most important in the airport setting.

Step 6: Develop Simulation Model

In this step, Simul8 is used to mimic the dynamic nature of passenger departure process, a simulation produced by SIMUL8 Corporation of Herndon, Virginia, USA. Simul8 provides is a time-based model and takes into account all the resources and constraints involved and the way various elements interact with each other as time passes (Simul8 Corp. 1999). Simul8 performs simulation after the researcher has drawn the process (from Process Mapping) and input the necessary quantitative data. The program emulates every significant step in the process and interactions between resources to provide an insight on how individual changes affect the whole process using Discrete Event Simulation (DES).

Step 7: Design of experiments

1. Measuring Variability

Design of Experiments (DoE) was first proposed in the 1920s by RA Fisher as a means of studying the effects of multiple variables simultaneously (Roy 2001). The next major advance in the technique came with the use of a methodology first developed Genichi Taguchi working in Toyota (Byrne and Taguchi 1986) who started research on DoE techniques in the 1940s.

The Taguchi Method is most easily explained with the flow diagram shown overleaf in Figure 4-2

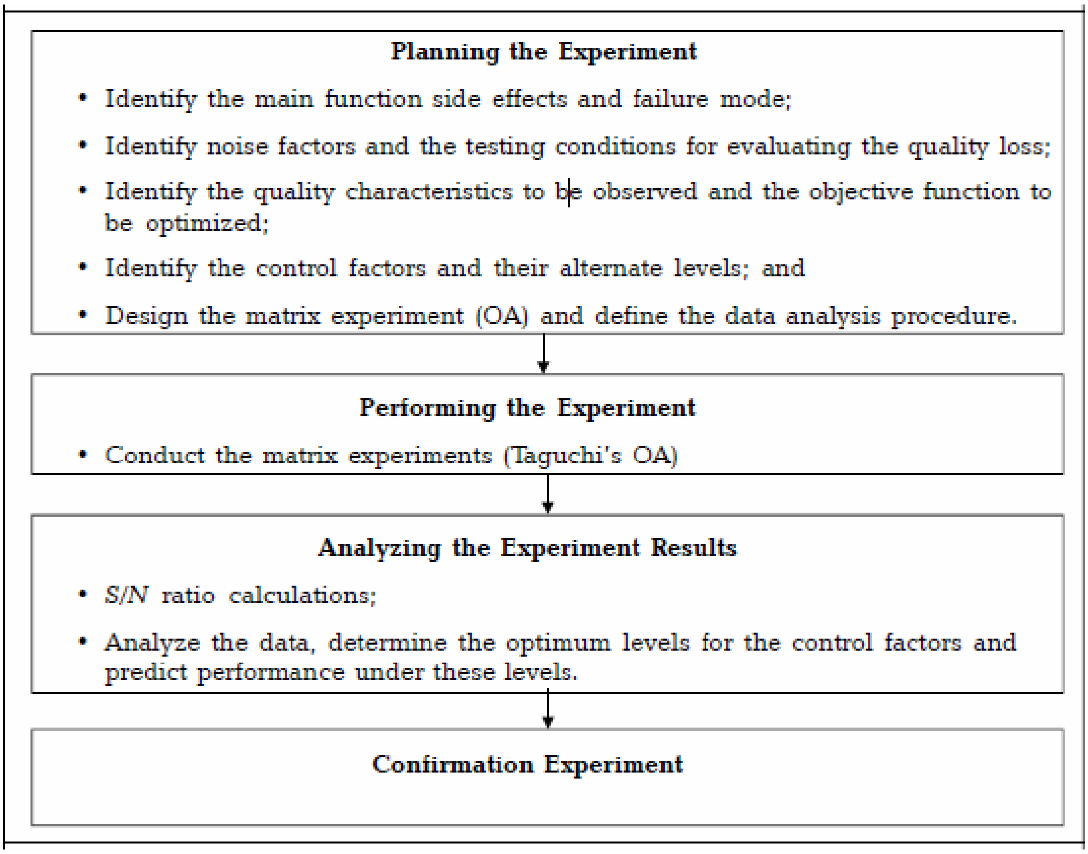

Figure 4-2 Flowchart of the Taguchi Methodology

Source: (Bagchi 1993)

The entire three-step Taguchi procedure is 1) system design, 2) parameter design, and 3) tolerance design in optimising the departure process (Byrne and Taguchi 1986). System design has already taken place. Thus the next key element is the second step: ‘Parameter Design’.

2. Parameter Design

The purpose of parameter design is to optimise the process’s functional characteristics and thereby have minimal sensitivity to ‘noise’. The Taguchi approach emphasises building robust quality into [products and] processes. This is achieved by carefully selecting parameters which best define key elements of the process and reduce variability when those parameters are performed (Sarin 1997). Taguchi refer to reduced variability as ‘on-target performance’ which associates a value to process quality by using the loss function. Taguchi proposes a holistic view of quality which relates quality to cost however one defines quality (Unal and Dean 1990). In this case one might define ‘quality’ in terms of passenger satisfaction, meeting the needs of the Airport Authority in terms of its economic model centred on payments from concessionary is or more specifically on the effective application of the Lean philosophy in reducing waste of resources. Taguchi helpfully defines quality saying “the quality of the product is the (minimum) loss important by the product to the society from the time the project is shipped” (Byrne and Taguchi 1986). While this describes a ‘product’ one may equally use it to describe a ‘process’ such as the functional elements at each processing station in the passenger departure process. Taguchi describes how economic loss is associative with losses which arise from rework, waste of resources, complaint and dissatisfaction costs, time and money spent by passengers during failing processes and the eventual loss of market share (Unal and Dean 1990). Thus process design significantly impacts on both quality and life cycle costs and Taguchi further notes that inspection and control can never completely compensate for poor design of the process (Bendell 1988).

Parameter design involves selecting the important parameters of a process and to achieve this one must find the optimal settings of controllable factors so that the final process design is robust when confronted by various uncontrollable factors (Rahman and Talib 2008). The underlying purpose is to increase awareness of the need to reduce variation and then to use a thorough systematic scheme of process optimisation which produces consistent performance and at the same time minimal variation, optimal cost and reduced cycle time (Unal and Dean 1990).

In this context, controllable factors are those which need to be optimised and over which the process designer has some control. Conversely, uncontrollable factors are those which are not under the designer’s control. In the case of the passenger departure process, uncontrollable factors include those which are imposed by external authorities or by other factors such as weather or air traffic controllers, mechanical problems or any of those which will affect the passenger departure. These include factors described in the system view in Section 2.6 in Chapter 2 which involve external factors and additionally some internal factors such as the relative unpredictability of passenger behaviour and movement in the areas between processing stations. The relationship among process parameters, if any relationship exists, is essentially nonlinear and cannot be uncovered if more than two levels of parameters are analysed at three levels (Byrne and Taguchi 1986). The design of any system, or in this case the end-to-end process, involves development under an initial set of normal conditions using the specialist knowledge of the parties involved in each processing station (Unal and Dean 1990). After system design, the next stage is parameter design.

Parameter design uses orthogonal arrays which list controllable factors and specify combinations of settings of the factor level so that each factor appears an equal number of times at each level. Orthogonal arrays have special properties which serve to reduce the number of experiments necessary and are efficient when compared to many other statistical designs. One can calculate the minimum number of experiments based on the degrees of freedom approach using the following formula:

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV}(L_i - 1) \qquad \text{(Equation 1)}$$

While the partly experimental approach selected for research design (Section 4.3.3) is concerned purely with research and knowledge building, the Taguchi approach is based on practicality. From this perspective, using the Taguchi methodology goes a step further than the standard DoE methodology as it seeks to develop process designed which are insensitive to noise factors and that remain on target with minimum variability (Sarin 1997). Noise factors are those factors which either cannot be controlled or are too expensive to control (Unal and Dean 1990). In practice, many organizations use trial and error or study a single parameter at a time. This leads to lengthy, expensive and time-consuming improvement processes or in many cases premature termination of the improvement process because of mounting costs. Unal and Dean (1990) noted that the study of thirteen design parameters at three levels would require 3^{13} (1,594,323) experiments to be carried out. The result is a process design which has not been optimised because optimisation of this type is unfeasible. Taguchi's approach to parameter design provides a realistic answer.

Taguchi's approach is the systematic and efficient method of determining parameters of cost and performance whose objectives is to select the best combination of controllable parameters which lead to the most robust solution with respect to noise factors. The Taguchi Method needs only a small number of experiments and statistically, conclusions drawn from such small-scale experiments are valid for the entire experimental subject.

The next step was for this researcher was to define which standard orthogonal array was to be used. This involves by counting the total degrees of freedom (*dof*) found in the research study. This determined the minimum number of experiments needed to be run to study the effects of the factors involved. The researcher allowed one *dof* for the mean value and then one *dof* for each variables running at different levels.

Thus the

> Total *dof* = (*dof* of overall mean + *dof* for number of variables running at different levels). (Equation 2)

Table 4-7 shows the rules for selecting standard orthogonal arrays when all experimental factors have only three levels (Rahman and Talib 2008).

Table 4-7 Rules for Selecting Standard Orthogonal Arrays

Number of Factors	Orthogonal Array to be Used
2-4	L_9
< 5	L_{27}

The next step was to conduct matrix experiments using simulation closely modelled on the flowcharts described in Figures 5-3 to 5-19 and then record the results. These results are shown in Chapter 6 and in Appendix B4.

Step 8: Result Analysis S/N, ANOVA

The regression technique for ‘analysis of variance’ (ANOVA) is often used to evaluate an experimental design (Upton and Cook 1996). ANOVA is a statistical method used to compare variance of the response magnitude in percentage terms for each parameter in orthogonal experimental data. Mathematically, ANOVA is similar to linear regression analysis because both are parts of the ‘general linear model’. They both achieve similar results.

While regression analysis is more flexible, ANOVA makes comparisons between groups and was specifically designed for analysis of experimental research. Regression analysis is more flexible because of the method's its ability to analyse various types of variables. Such flexibility is not needed when checking experimental models of this type. For this reason ANOVA has been commonly used in this context by various researchers (Athreya and Venkatesh 2012, Çiçek, et al. 2012, Singh and Kumar 2006). Consequently, this researcher used ANOVA to analyse experimental results. These will be reported and analysed in the Chapter 6.

After the experiment was run, the researcher analysed results using signal-to-noise ratio (S/N) calculations. Taguchi (Byrne and Taguchi 1986) made various recommendations on the several models of S/N ratios so that each could serve as a data summary which can combine to characteristics into which is the desired one (Rahman and Talib 2008, Roy 2010) such as 'on-target', 'above target' or 'below target'. In this case, the most appropriate model was 'on-target'. In this model (Equation 3), 'n' continuous observations are made and where y_1, y_2, y_3 ….. y_n represent the multiple values of performance characteristic 'Y' produced by experimental data. The 'on-target' value is 'τ'. The researcher maximised S/N as follows (Rahman and Talib 2008):

$$S/N \; = 10 \, log_{10}\left[\frac{\tau^2}{S^2}\right] \text{ where, } S^2 = \sum_i \frac{(y_i-\tau)^2}{(n-1)} \qquad \text{(Equation 3)}$$

In fact, the calculation was performed by the Minitab program which produced graphical output of signal-to-noise ratio to facilitate better analysis. Thus the S/N ratio took both the mean and the variability into account. Experiments aimed to maximise the S/N ratio. This was equivalent to minimising the loss. This enables the use of S/N ratios to assure robustness of the process independent of target setting (Rahman and Talib 2008).

Step 9: Develop Rules for PDP Improvement

This step focuses on developing rules for PDP improvement based on based on the actual physical capacity of the terminal as an example. It is needed to confirm the basic principles obtained from Taguchi experiments and ANOVA analysis. The developed rules can also be used to show the significant improvement could be achieved, by applying them in particular circumstances. (See section 7.2)

Step 10: Link Rules to Simulation Model

This step focuses on link the developed rules to simulation model through programming facilities available in the Simul8. This is needed to reduce passenger waiting time by affecting use of the resources such as staff or triggering the faculties of the terminal such as opening more check-in counter by controlling the rules. (See section 7.3)

Step 11: Re-Run Experiments with Developed Rules to Improve PDP

This step is needed to improve the queuing characteristics throughout the 24-hour period using the developed rules following the default run. The main elements of the improving are Mean and Maximum Queuing Times which are key measures of improvement of the process. The simulation model produces flows of passenger on a daily (24 hr) basis taking into account daily fluctuations/peaks in demand after scenario. (See section 7.4)

4.7 Chapter Summary

This Chapter illustrates the proposed research methodology to improve the PDP flow. Research questions and objectives were defined and from them the research philosophy, research approach and research strategy were developed. Research steps adopted in this research are also explained. Next chapter will presents and discusses the data collection methods.

Chapter 5 : Data Collection-Field Study Data

5.1 Overview

This Chapter presents and discusses data collection methods adopted in this research. It provides a detailed explanation of why certain data were collected, what data were collected, where these data were collected and how these data were analysed. The collected data consists of qualitative and quantitative data that are needed to achieve the research aims and objectives.

5.2 Data Collection

Data collection is step 3 of the research methods used in this research. Previous chapter provided justifications of the data collection tools used. This section presents and discusses in details with examples the questions have been asked, personnel participated in data collection process.

5.2.1 Qualitative Data Collection

A principal concern was to collect information about the local and international regulatory framework that governs all airport operations and all processing stations which could directly affect Lean improvement methods. The research also recognises new regulations may be imposed at any time, at short notice. Two methods achieved knowledge of these regulations:

1. A detailed literature survey which focussed on regulatory matters (Section 2.7)
2. Unstructured interviews with managers concerning with the different parts of Terminal 3 in Abu Dhabi Airport, such as Check-In, Emigration, Security and Boarding. Interview structure has been designed in this research to explore key personnel of the departure passengers' process opinions and views on the process. The interview has eight questions, and these questions have been asked to all the interviewees. These questions are:

Q1: What are the main barriers for passengers flow in airport terminal 3?

Q2: What are the main wastes in resources (human and physical) in the passenger's departure process?

Q3: What is the role of level of experience of the employees on the process cycle time?

Q4: What % of overweight baggage passenger in respect of check-in and how they process it?
Q5: What % of visa and passport related issues with respect of emigration process and how they deal with such issues?

Q6: What % of security, in case of high risk security passenger, or random security inspection in the passenger flow process and how they deal with such issues?

Q7: What are the main passengers' group sizes travelling together in the departure terminal 3?
Q8: What is the impact of transfer passengers from other flight on the passenger's departure flow?

Table 5-1 shows the key personnel interviewed in this research and the sample size. The total number of the interviewees was 9. The interviews were carried at the convenient date and time. All the interviews carried out in the airport at the the interviewees office and each interview took from 30 to 45 minutes.

Table 5-1: Interview sample

Key Personnel	Sample Size
Airport Services Quality Manager	1
General Manager: Engineering Services and Quality Manager	1
Quality Assurance Controller	1
Executive Assistant VP of QA and Environment, Health and Safety Office	1
Senior Manager Business Processes and Processors	1
Check-in Desk Operations Manager	1
MIS Manager	1
Immigration Controller	1
Security Station Controller	1
Total number of interviews	9

3. Observation; observations were conducted along the lines of questions being asked during the interview process to validate the responses and also to understand the DPD flow, which is reflected in the process mapping.
4. Documentary Analysis; further understanding of procedures need to be followed with different passenger classes such as first class, business and economy class. For example, queuing in the waiting area for the first class Check-In station should

not exceed 30 Pax. This also supplemented the information collected from interviews and observations and was used to develop the default rules (Section 5.6.3).

5.2.2 Qualitative Data Validation

The qualitative data has been validated using the following steps:

1. Pilot study of the interview carried out before the actual of the interview' the pilot carried out with one of the senior manager of the airport to ensure the wordings, structure and the questions reflect the research objectives.

2. Careful triangulation was used as the principal method of overcoming validity errors of the qualitative data. This involve asking various parties involve in the process whether participants or nonparticipants in the process or processing station under observation disclosed any potential errors in observation which could then be overcome. This includes interviews with key personnel, documents and analysis and observation to ensure consistency. This researcher developed relationships which enabled different teams, disciplines or sections to be questioned separately and at different points in time. Only when results of mixed-methods which involved rich questioning and quantitative results uncovered no apparent discrepancies, were they accepted.

5.2.3 Quantitative Data Collection

Quantitative data has been collected using PDA and the airport database.

1. PDA; The check in process in PDA device is shown in the Figure 5-1. The process is simply waiting at the beginning of the passengers queue and waits until the passenger leaves the passengers queue to the check-in counter as shown in the figure 5-1. This is followed by clearly identifying the last passenger in the queue and then by setting the time of identification. This followed by counting the number of passengers in the queue and the number of open counters in the check-in. The following entered on the software at the stage, total number of passengers in the queues, number counters opened. Once these are set, the total number of passenger queuing for the Airline and queue number is automatically generated by the software. Then the observer needs to set whether the "last passenger" in the queue arrives at the counter in less than 10 minutes or over 10

minutes. The same setting and procedure adopted in for other stations such as the immigration, passport control and security.

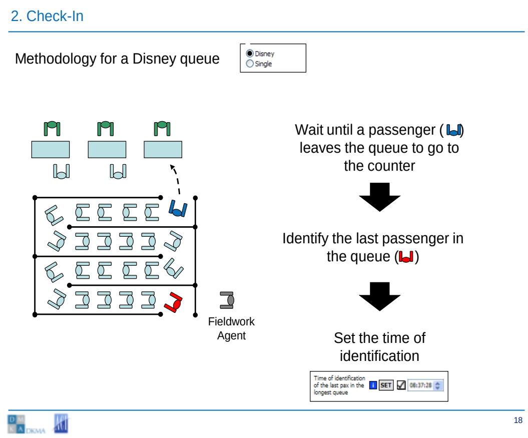

Figure 5-1 Check in process in PDA device

2. Airport Database; Airport database was studied for past demand related to different classes, which was used to design the experiment by generating the daily demand distributions. For example, minimum daily demand for economy class (Table 5-5) is 4,944, which is derived from the flight schedules October, November and December 2013 (Appendix B3).

5.2.4 Quantitative Data Validation

The data from the PDA are accurately measured what they were intended to measure due to the design of the PDA. The data produced by the PDA are what the simulation needed to run.

5.3 Developing Process Mapping – Terminal 3

5.3.1Traditional Check-in: Economy Process Mapping

This section presents briefly explanation of the economy check-in process mapping that developed for this station and from Lean aspect this has provided an insight to value-added and non-value added activities on the each process on DPD flow (as identified in Section 2.5). The passenger on the arrival to the terminal for check-in will be in three different modes. The passenger either ready to check-in or not ready in this case the passenger needs to wait in the designated waiting area, or the passenger is in remote check-in. The following steps needs to be followed for ready to check-in passenger

1. The passenger needs to be checked where the passenger local or not.

2. The check-in counter needs to check the passenger ticket documents, valid ticket.

3. The check-in counter needs to check the passenger passport and visa. The passenger needs to have valid passport and valid visa for the destination country.

4. Once the passenger documents checked, the passenger luggage weight and type needs to be checked.

5. Checking the flight manifest.

6. The counter desk then needs to enter the passenger information in the system.

7. Checks for alert, in case of problem within the passenger this will be identified by the system.

8. The counter can ask the passenger legal questions. This may include reason for the visit or health checking or question relating to the visa.

9. The passenger then asked on his preferred seat and any dietary required during the flight.

10. Checking the passenger hand luggage, the luggage that needs to be with passenger during the flight.

11. Weight hold luggage, the luggage needs to be weighted to check they are within the limit set by the passenger ticket conditions.

12. Print and affix labels for the passenger luggage

13. Return hand luggage after labelling

14. Switch holds baggage to main conveyor.

15. Print the passenger boarding card

16. Return passenger documents with the board card.

5.3.2 Check-in Economy Flow Chart Validation

Once the process mapping flow chart is completed a validation process for the chart carried out to ensure the validity and accuracy of the flow chart. The validation process used for the all the stations are the same. This section presents briefly the validation process use to validate the check-in process for economy-class station. It is important to stress the same procedure and approach has been used to validate the other stations flow charts process mapping. Different resources have been used to ensure validity of the process. The validation process steps include the following:

1. Check the developed process mapping with physical structure flow of the terminal 3. This has been achieved by checking the terminal 3 documents such as the terminal design and layout.

2. Face to-face meeting with the check-in economy station manager. The flow chart has been discussed with the manager to check the process mapping and comments in each step of the process to ensure reliability and accuracy of the developed flow chart.

3. Personal observation: The researcher also observes personally the flow chart process step by step to confirm the accuracy and the early discussions with the station manager and the document.

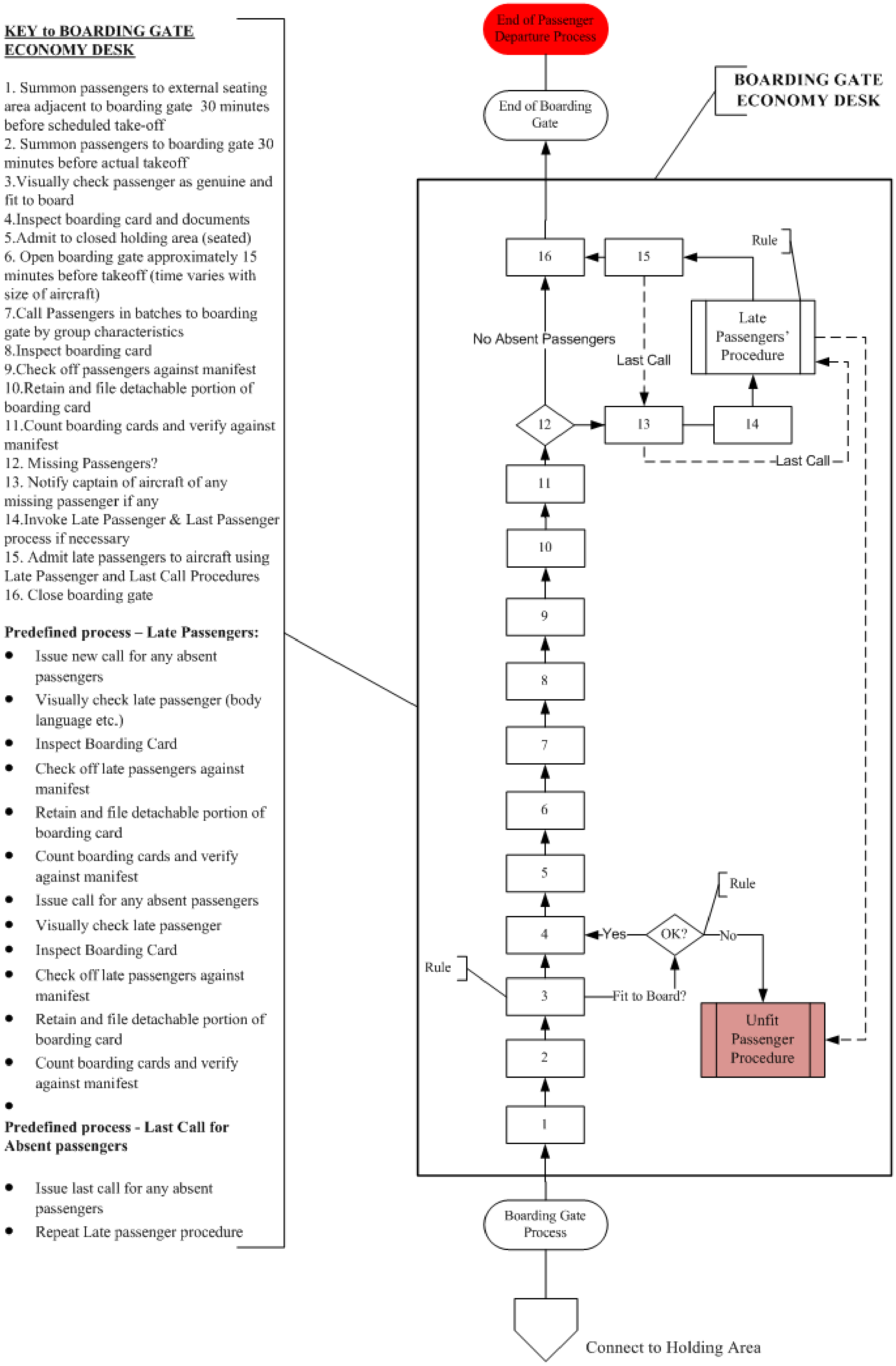

Figure 5-2 Boarding Gate: Economy

Here, the complete Economy-Class passenger departure process is shown starting at the point just before boarding at the boarding gate. In each case, such as below circulation, services and commercial concession areas are shown between processing stations. It is unnecessary to show these in detail as the time passengers spend in them is variable and within limitations, at the discretion of the passenger who may choose which activities they wish to use in these areas.

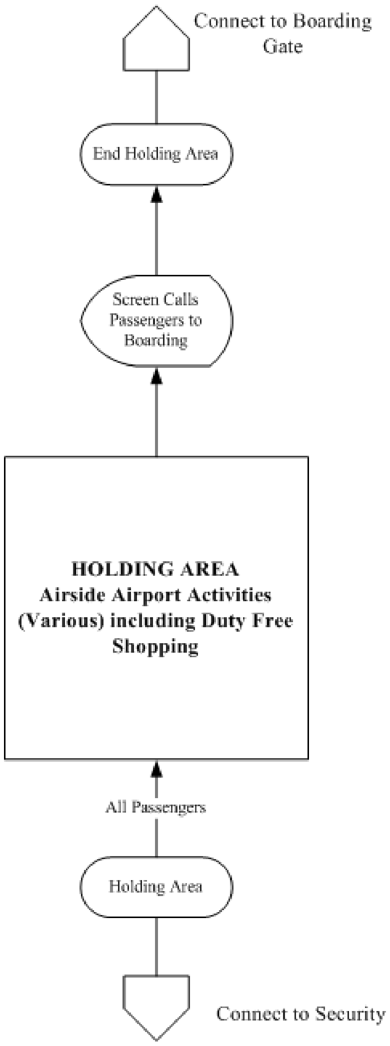

Figure 5-3 Airside Holding Areas between Boarding Gate and Security Including Commercial Areas

In each case, the symbol for the process which may terminate passengers' right to travel is shown in 'deep pink', as for example 'further action' by external police or security authorities in Figure 5-5. Where a number of activities take place at the processing station, the processing station itself is shown surrounded by a bold line and the activities which take place within it are listed in detail. In each case, a key to sub-processes is shown on the left. The flow model indicates whenever a predetermined rule leads to an operator using predefined process, normally shown as a bulleted list in the key. Transit passengers normally join the departure process at the boarding gate and feed through the holding and circulation areas shown in Figure 5-4 though some enter through security.

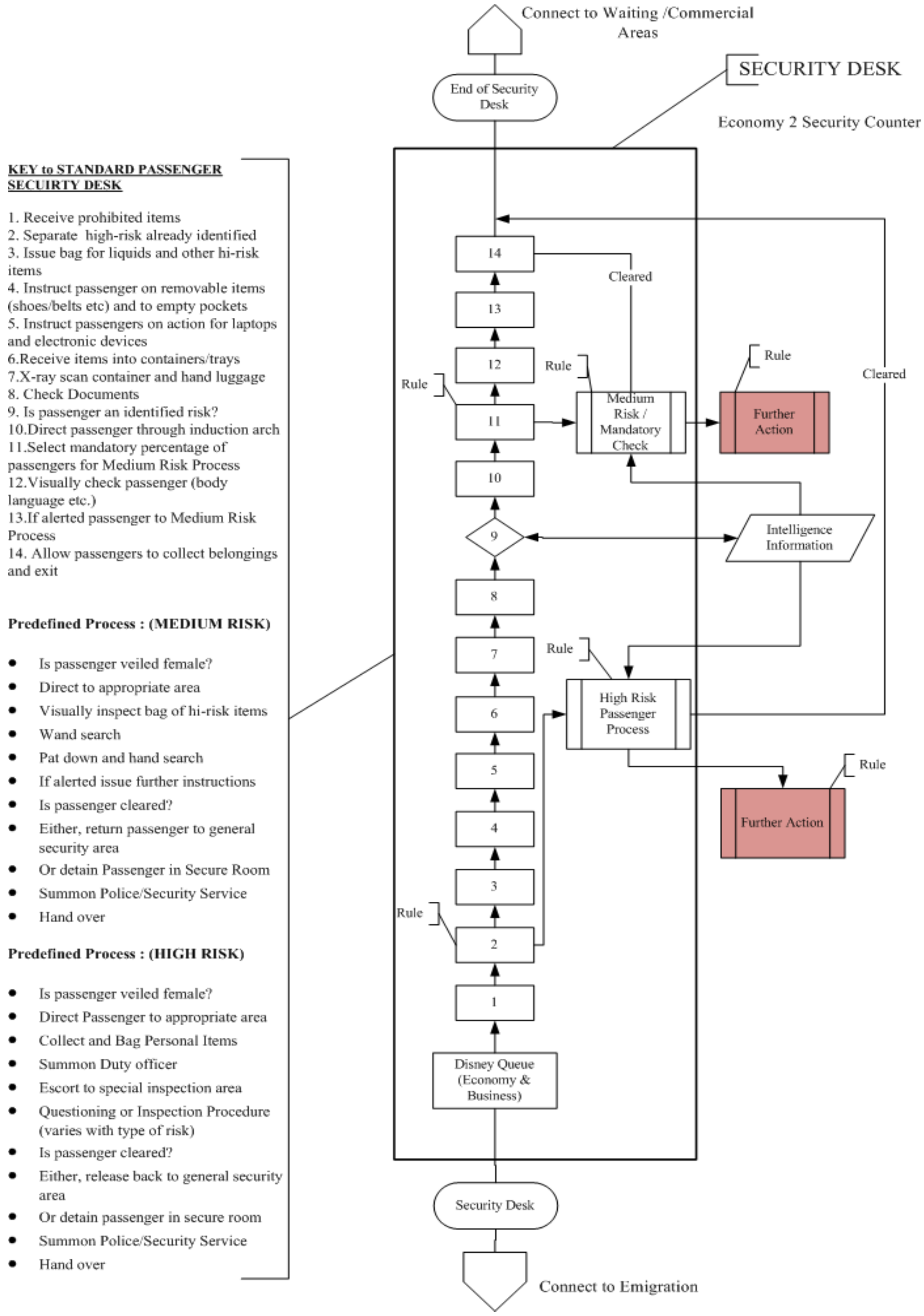

Figure 5-4 Security Gates: Economy

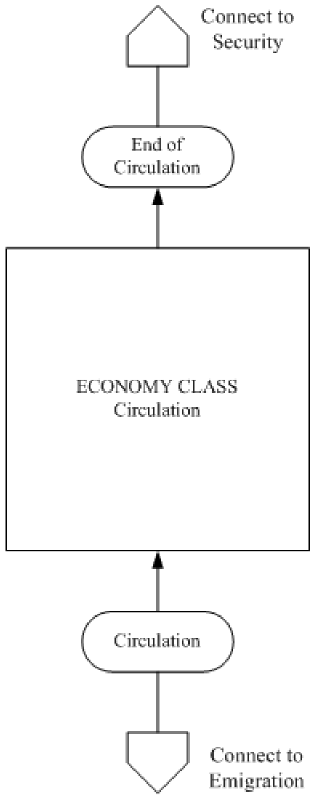

Figure 5-5 Airside Circulation Area between Security and Emigration: Economy

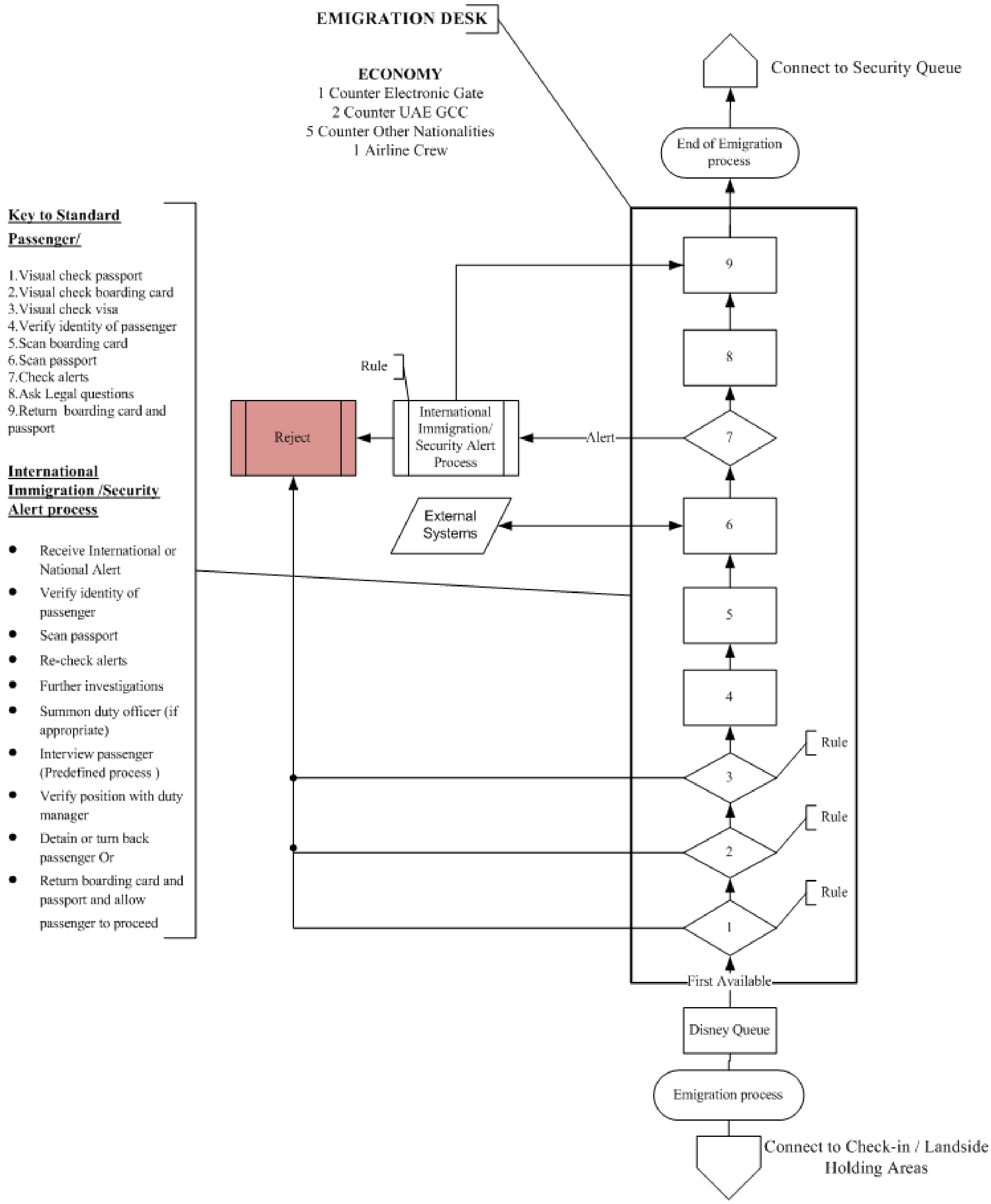

Figure 5-6 Emigration Desk: Economy

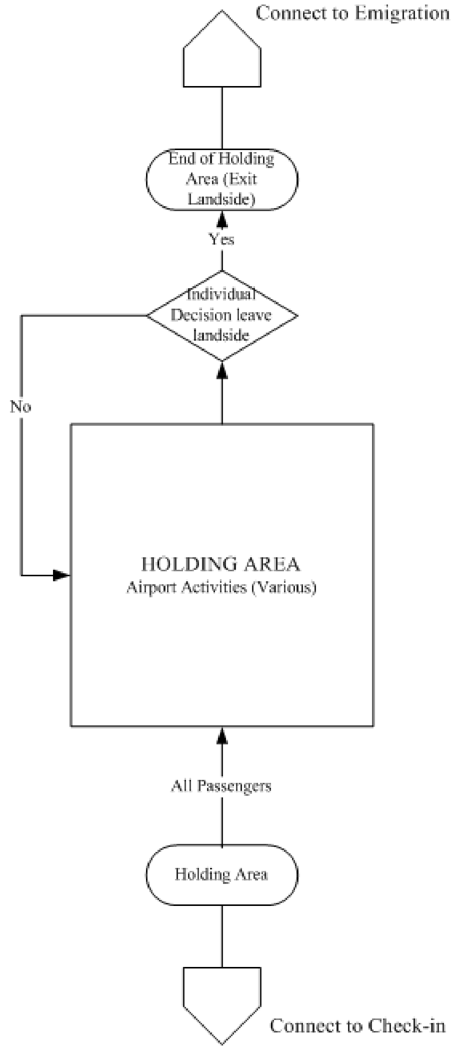

Figure 5-7 Landside Holding, Circulation and Commercial Areas

Figure 5-9 shows the start of the departure process, as standard check-in. The green oval marks the limit of the passenger departure process under consideration in this research, just as the red oval in Figure 5-3 shows the other limit.

Abu Dhabi Airport, like other major airports offers several alternative check-in processes. Only those two offered within Terminal 3 of the airport complex are shown here in Figures 5-10 & 5-11. Both Figures 5-10 & 5-11 may individually replace Figure 5-9 if a passenger uses these alternatives.

Because they are essentially the same, though in different physical locations, the processes shown in Figures 5-10 & 5-11 are also found in First and Business-Class departure areas.

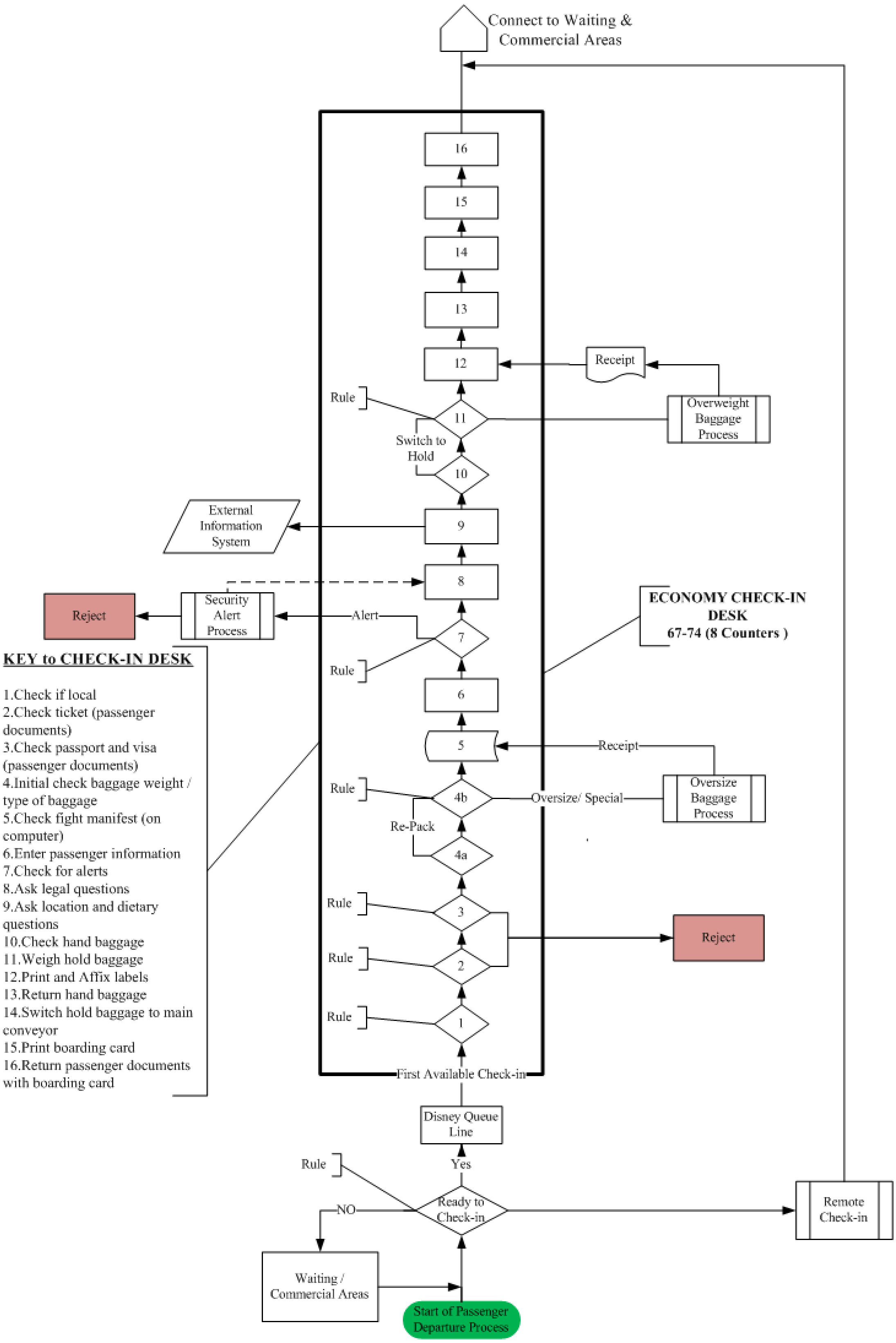

Figure 5-8 Traditional Check-in: Economy

Alternative Check-in Processes

(Similar processes exist in First and Business-Class areas)

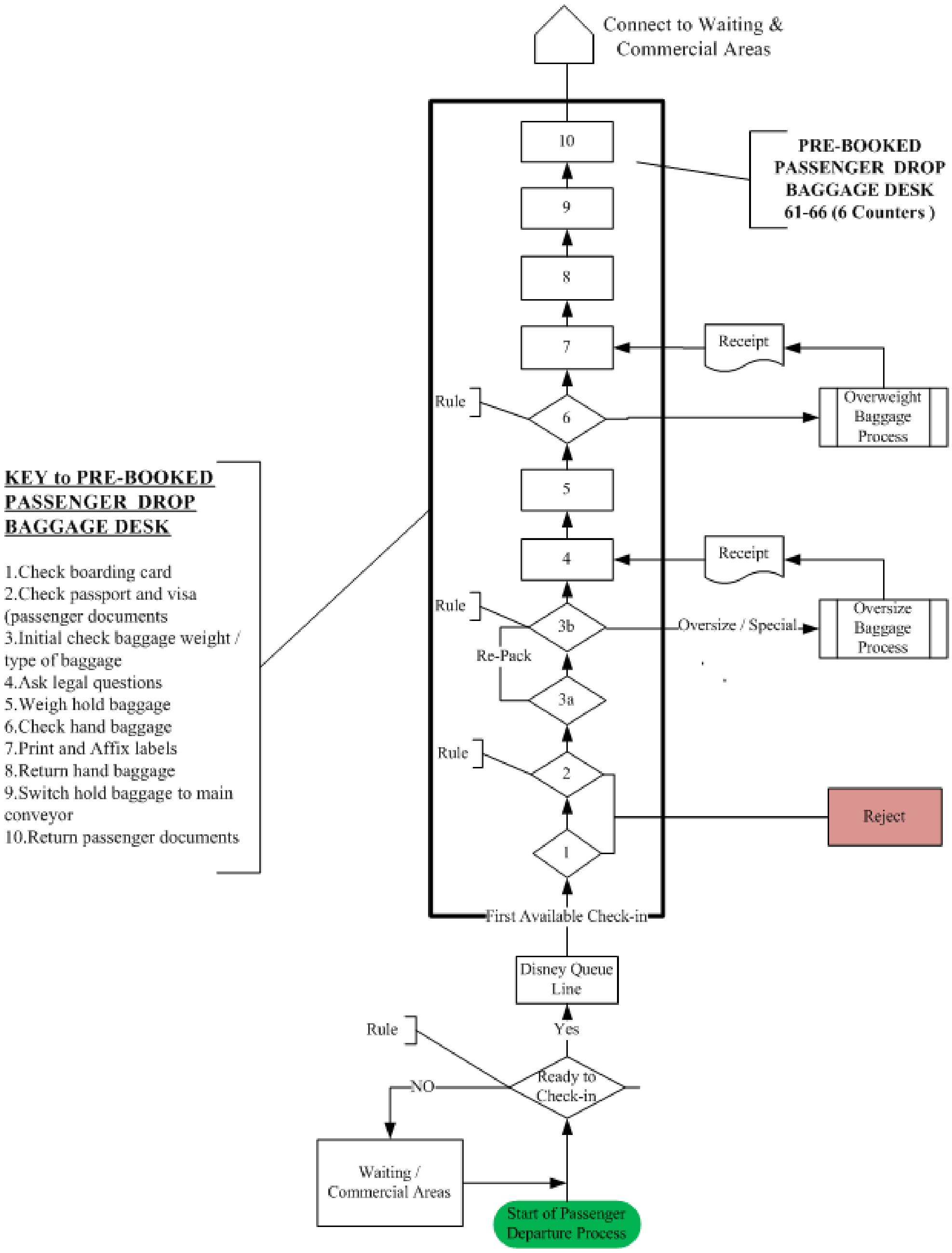

Figure 5-9 Alternative Check-in Process: Baggage Drop

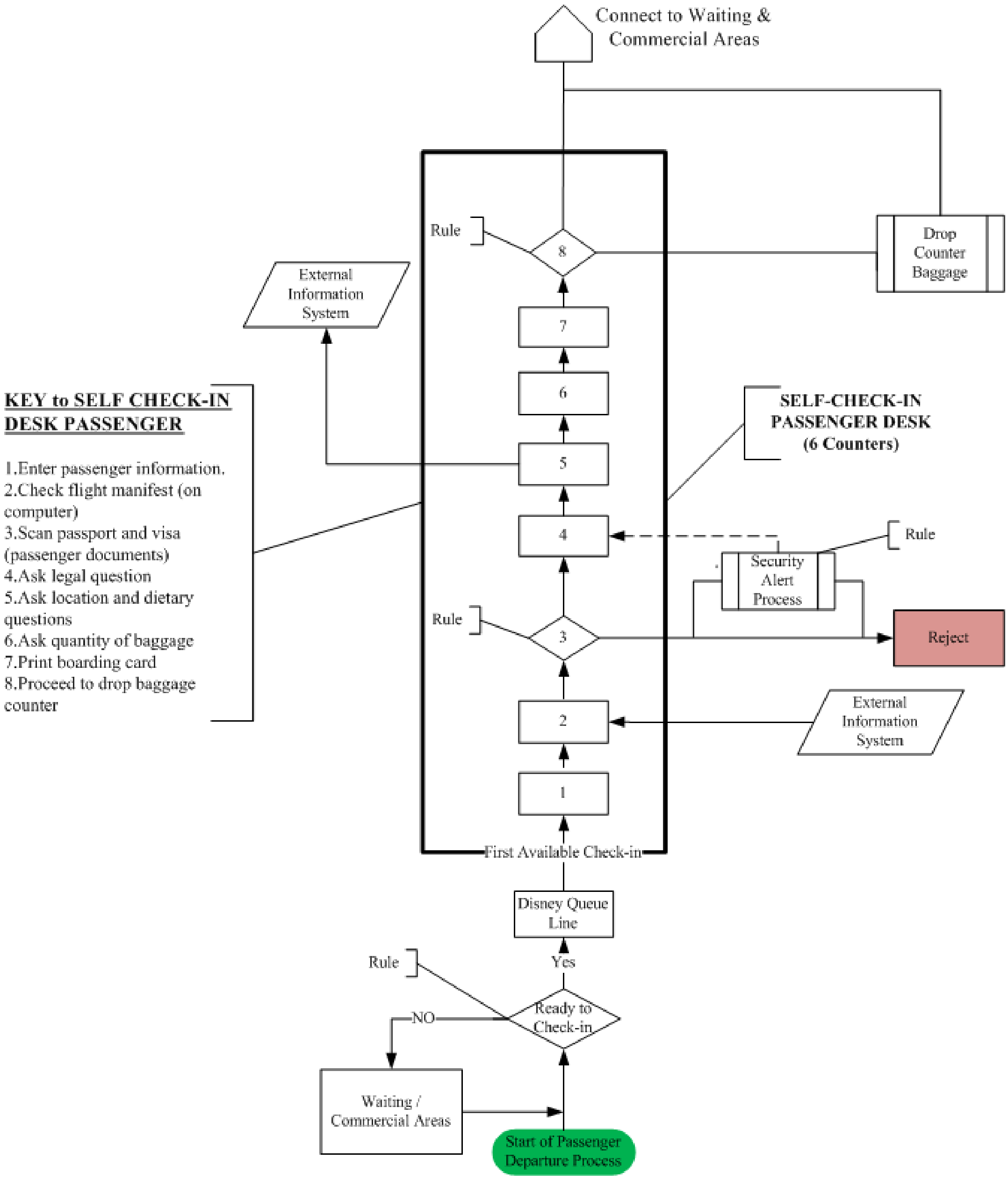

Figure 5-10 Alternative Check-in Process: Self Check-in

First and Business-Class

KEY to BOARDING GATE DESK – FIRST & BUSINESS CLASS

1. Summon passengers to First /Business Class boarding lounge 30 minutes before actual takeoff
2. Visually check passenger as genuine and fit to board
3. Inspect boarding card and documents
4. Admit to closed holding area for immediate boarding
5. Call Passengers in batches to boarding gate
6. Inspect boarding card
7. Check off passengers against manifest
8. Retain and file detachable portion of boarding card
9. Count boarding cards and verify against manifest
10. Missing Passengers?
11. Notify captain of aircraft of any missing passenger if any
12. Invoke First/Business Class Late Passenger & Last Passenger process if necessary
13. Admit late passengers to aircraft using Late Passenger and Last Call Procedures
14. Close boarding gate

Predefined process – Late Passengers:

- Issue new call for any absent passengers
- Visually check late passenger (body language etc.)
- Inspect Boarding Card
- Check off late passengers against manifest
- Retain and file detachable portion of boarding card
- Count boarding cards and verify against manifest
- Issue call for any absent passengers
- Visually check late passenger
- Inspect Boarding Card
- Check off late passengers against manifest
- Retain and file detachable portion of boarding card
- Count boarding cards and verify against manifest

Predefined process - Last Call for Absent passengers

- Issue last call for any absent passengers
- Repeat Late passenger procedure

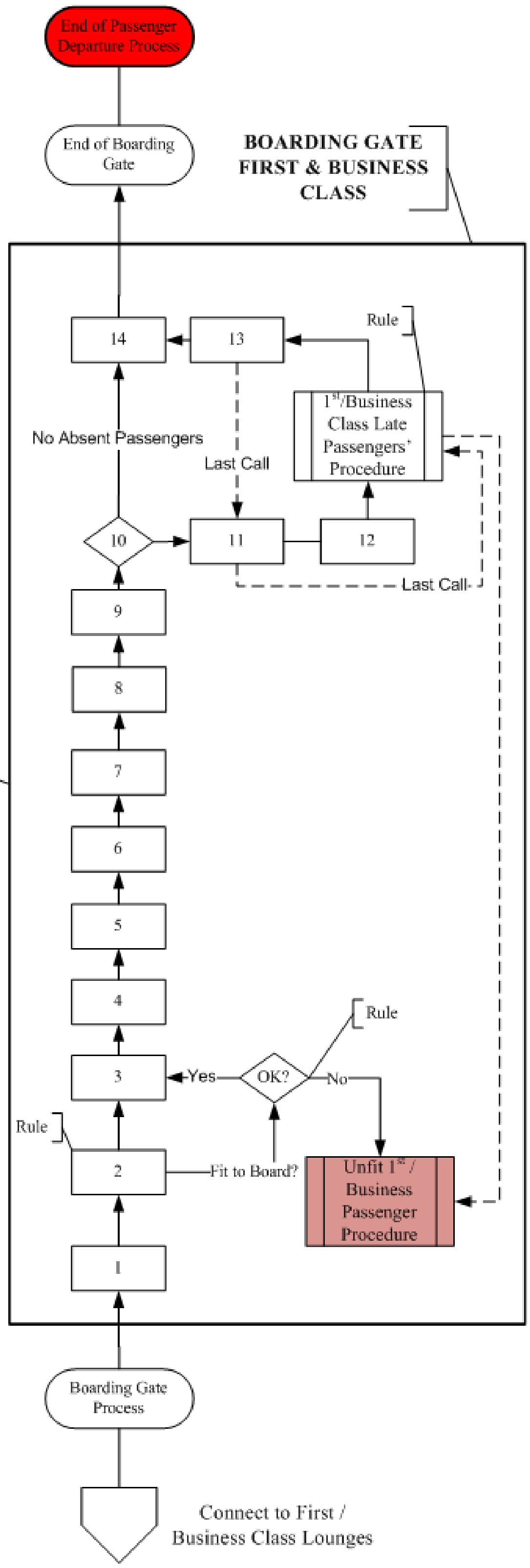

Figure 5-11 Boarding Gate: First & Business-Class

Although activities at each processing station are essentially the same in all three classes, levels of services demanded by First and Business-Class passengers differ marginally from Economy-Class. In some cases, especially check-in, there might be slight variations between First and Business-Class. These are shown in the process maps in Figures 5-18 & 5-19.

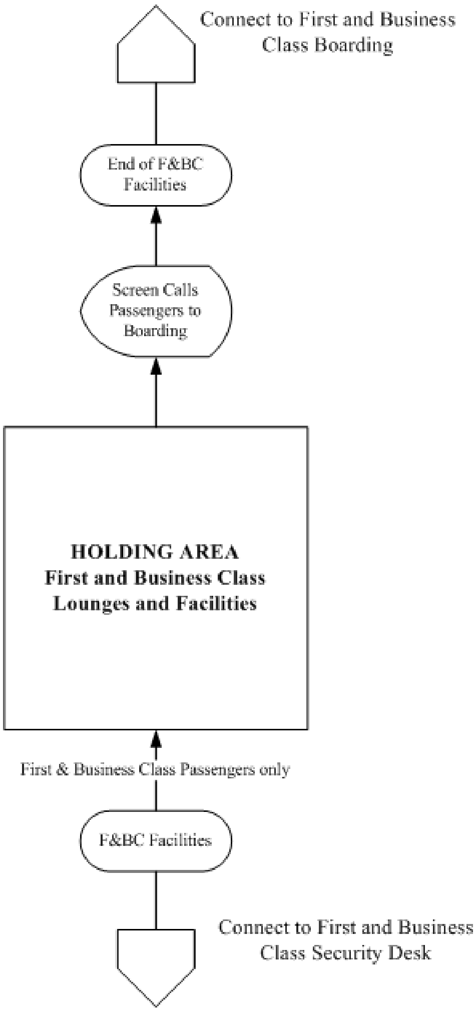

Figure 5-12 Airside Holding Areas between Boarding Gate and Security: First & Business-Class

First and Business-Class passengers are provided with different airport facilities and circulation areas from those for Economy passengers. Consequently these are shown as separate links between processing stations. Nevertheless, First and Business-Class passengers may also use the circulation areas and other facilities provided for Economy-Class passengers, though most do not.

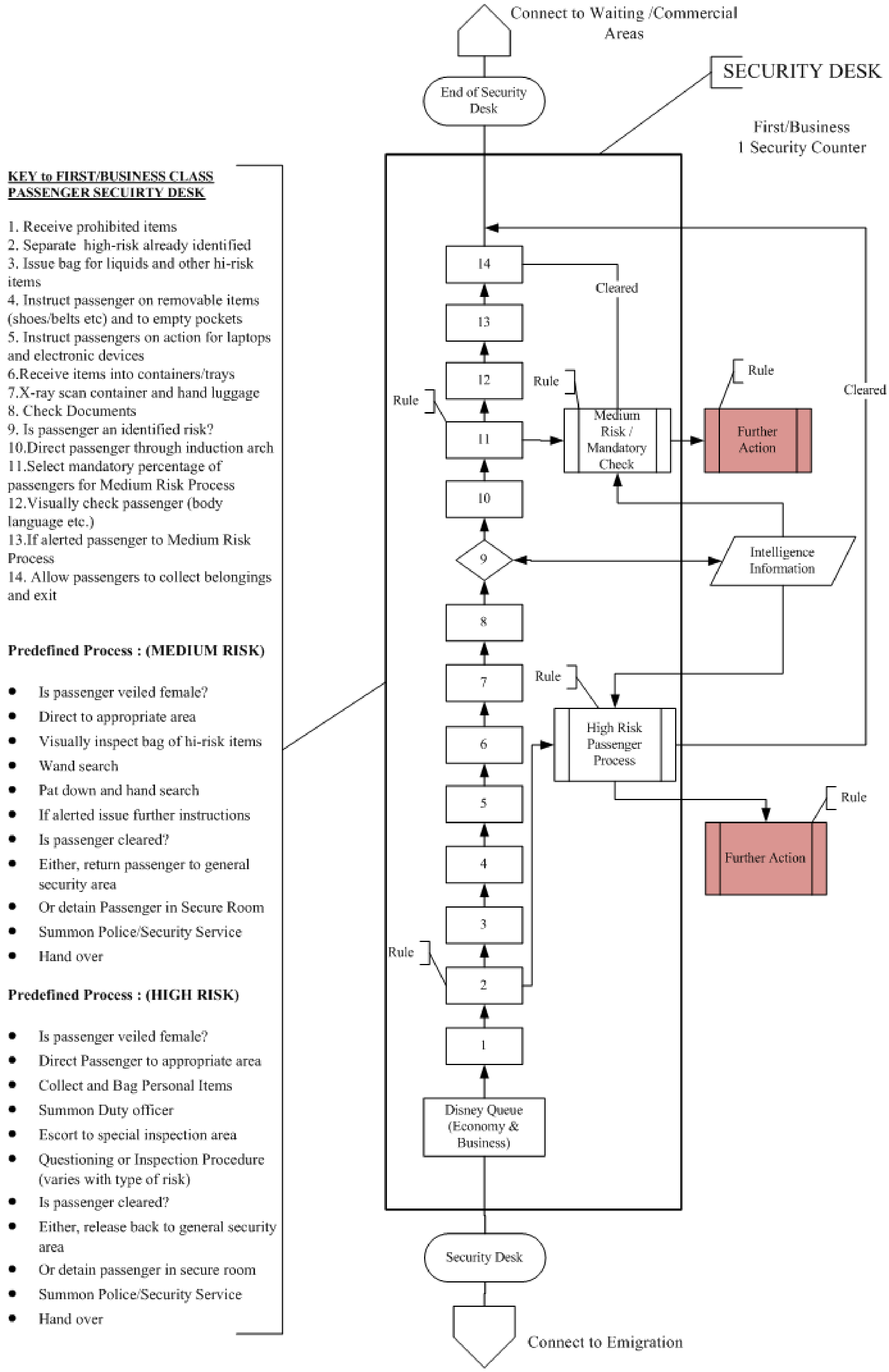

Figure 5-13 Security Gates: First & Business-Class

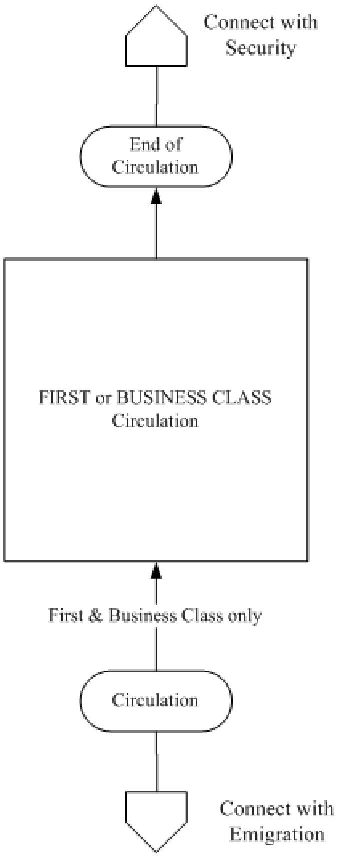

Figure 5-14 Landside Holding, Circulation and Commercial Areas: First & Business-Class

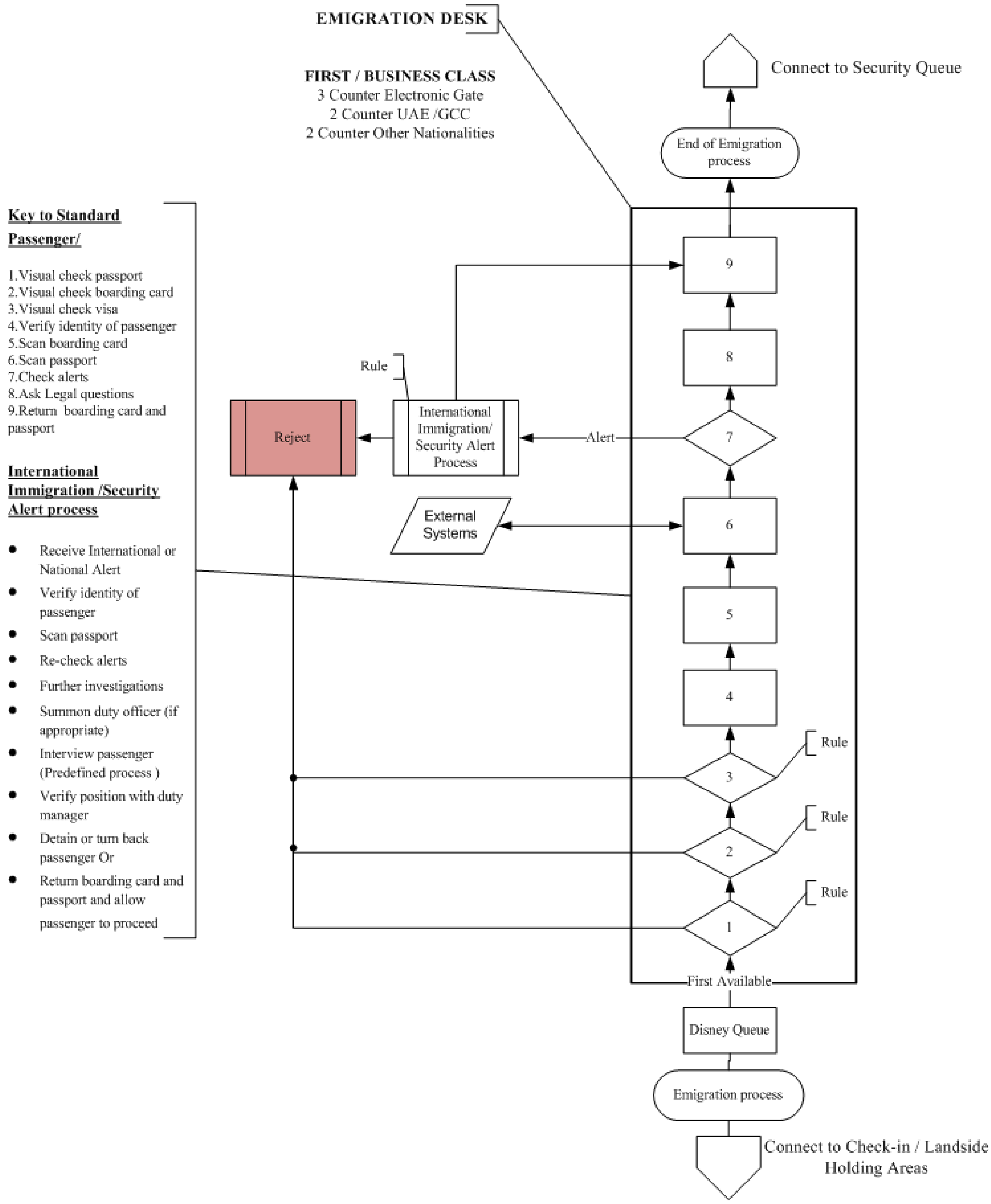

Figure 5-15 Emigration Desk: First & Business-Class

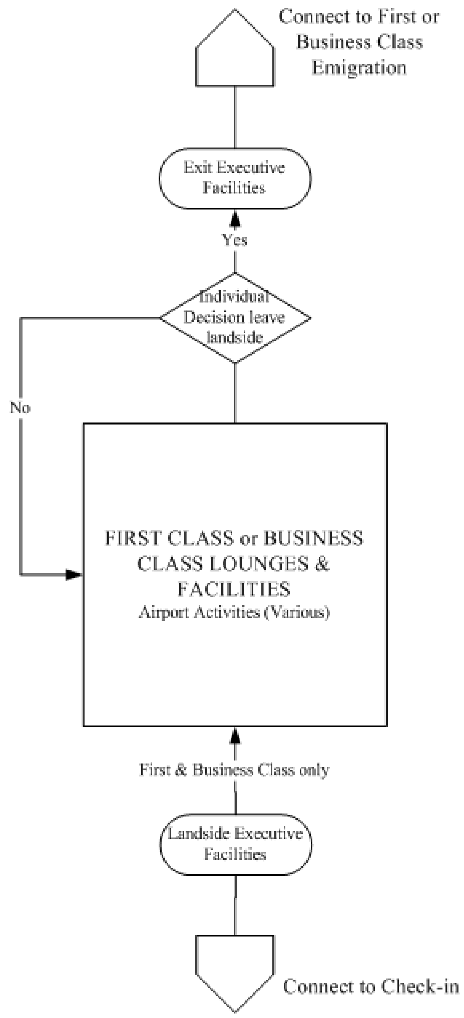

Figure 5-16 Landside First & Business-Class Amenities, Circulation and Commercial Areas

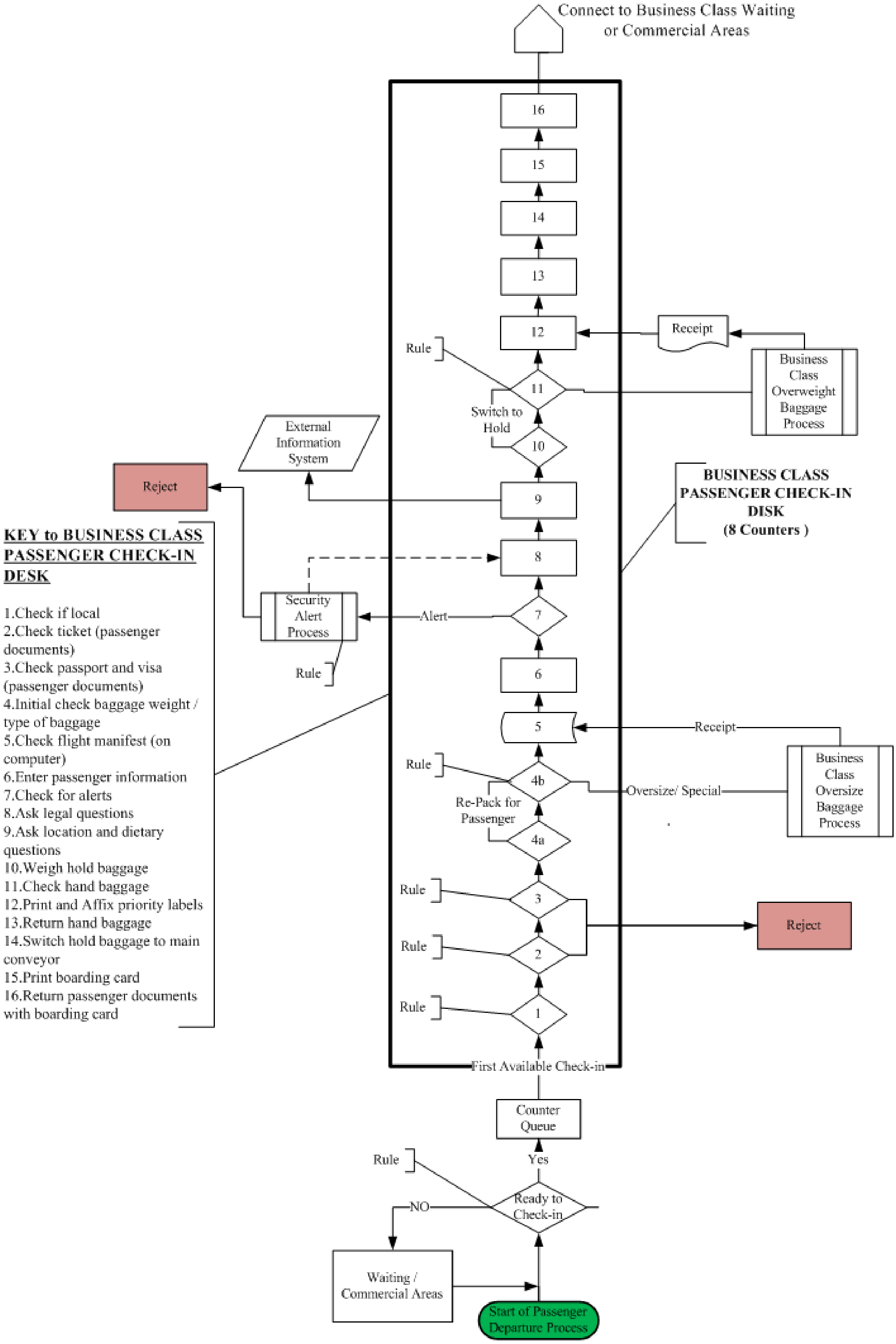

Figure 5-17 Traditional Check-in: Business-Class

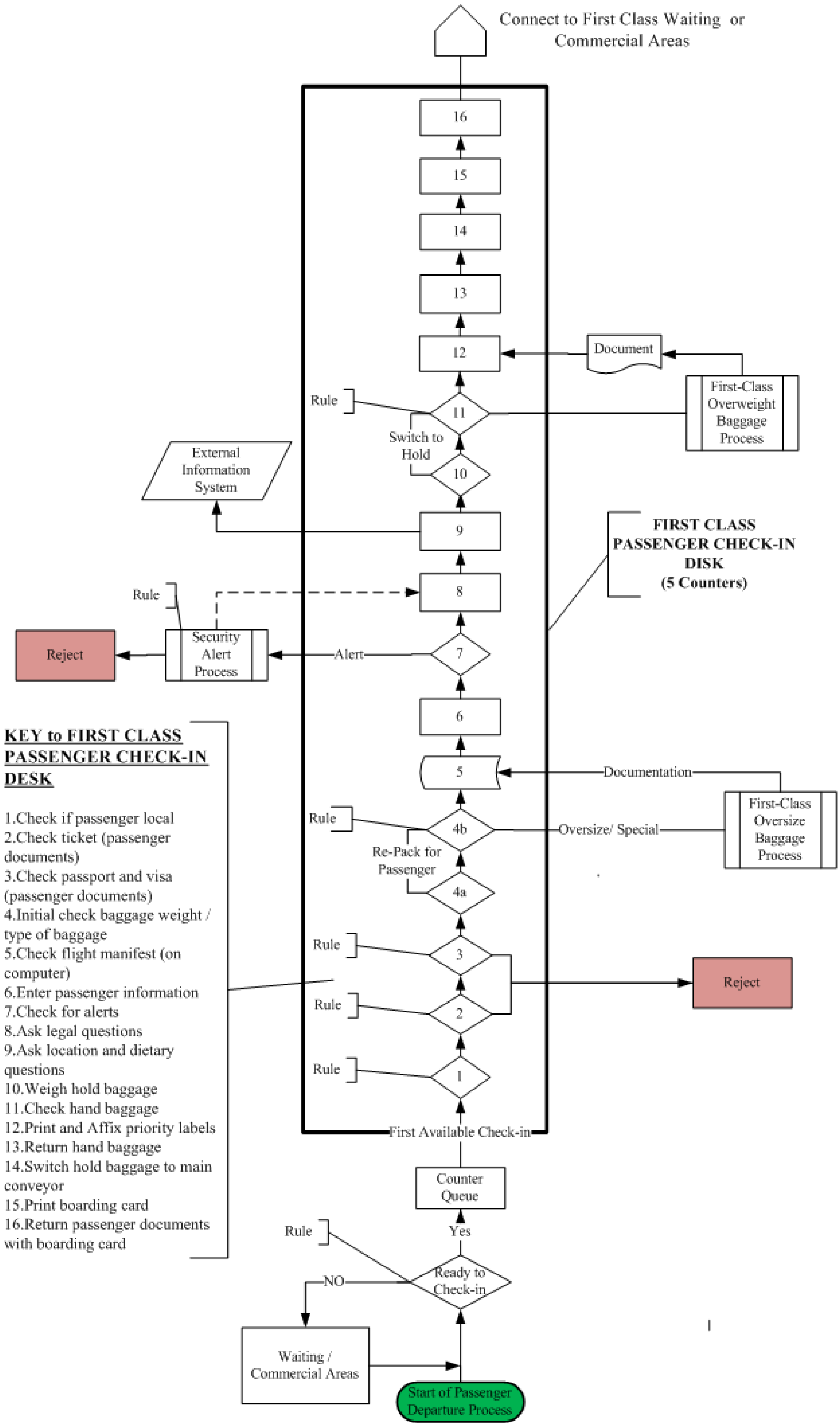

Figure 5-18 Traditional Check-in: First-Class

5.4 Develop Simulation Model

In the case of this research Table 5-2 shows details of each of the modelling elements in the passenger departure process.

Table 5-2 Modelling Elements

Modelling Elements	Model Type	Attribute	Value (Variability Levels)			Description
Waiting Commercial Area Economy	Queue	Queue Size	Infinite			Quantity Number of passenger waiting based on their flight call
Waiting Commercial Area First/ Business-Class						
Waiting Economy Check-in Desk	Queue	Queue Size	Infinite			Quantity Number of passenger waiting for check-in desk
Waiting Economy Self Check-in						
Waiting Economy Drop-Baggage Desk						
Waiting First Check-in Desk						
Waiting Business Check-in Desk						
Economy Check-in Desk	Process Station	Active Stations	8	5	3	All values vary for each experiment, which is derived from Taguchi array (Appendix B4)
		Cycle Time (Min^s)	2.76	1.93	1.56	
		Rework (%)	5%	3%	1%	
		Reject (%)	0.3%	0.2%	0.1%	
		Batch Size 8,3,1 (units)	10%,70%, 20%	8%,75%,17 %	2%,88%, 10%	
		Baggage Status	90%,8%,2 %	90%,8%,2%	90%,8%, 2%	
		Percentage of Operatives with experience level	Low 5%	Normal 80%	High 15%	
		Daily Demand	4,944	4,091	3,515	
		Weekly Demand	34,606	28,639	24,605	
		Monthly Demand	150,370	124,445	106,913	

Modelling Elements (cont'd)	Model Type	Attribute	Value (Variability levels)			Description
Reject Economy Check-in	Work Exit Point	Routing Out				Derived from Taguchi array and vary for each experiment.
Reject First/ Business Check- In						
Waiting for Immigration Desk Economy	Queue	Queue Size	Infinite			Number of passengers waiting for immigration desk
Waiting Immigration Desk First/ Business						
Reject Immigration Economy	Work Exit Point	Routing Out				Derived from Taguchi array and vary for each experiment
Reject Immigration First/ Business						
Immigration Desk Economy	Process Station	Active Stations	8	3	2	
		Cycle Time (Min^s)	1.3	0.75	0.55	
		Rework (%)	0.23%	0.19%	0.15%	
		Batch Size8,3,1 (Units)	10%,70%, 20%	8%,75%,17%	2%,88%,10%	
		Percentage of Operatives with experience level	Low 5%	Normal 80%	High 15%	
		Reject (%)	0.18%	0.15%	0.12%	
Immigration Desk First/ Business	Process Station	Active Stations	4	2	2	
		Cycle Time (Min^s)	1.3	0.75	0.55	
		Rework (%)	0.12%	0.10%	0.08%	
		Batch Size8,3,1 (Units)	3%,18%,79%	2%,15%,83%	1%,12%,87%	
		Percentage of Operatives with experience level	Low 5%	Normal 80%	High 15%	
		Reject (%)	0.10%	0.08%	0.06%	

Modelling Elements (cont'd)	Model Type	Attribute	Value (Variability Levels)			Description
Immigration Alert Process Economy	Process Station	Cycle Time	Average 10 Min			Rework for any passengers with immigration issues such as Visa passport
Immigration Alert Process First/ Business						
Waiting Security Economy	Queue	Queue Size	Infinite			Quantity number of passenger waiting for security Machine
Waiting Security First/ Business						
Security Economy Machine	Process Station	Active Stations	2	2	1	All values vary for each experiment, which is derived from Taguchi array
		Cycle Time (Min^s)	0.93	0.36	0.11	
		Rework (%)	20%	18%	15%	
		Percentage of Operatives with experience level	Low 5%	Normal 80 %	High 15%	
		Reject (%)	0.22%	0.18 %	0.14%	
Security First/ Business Machine	Process Station	Active Stations	1	1	1	All values vary for each experiment, which is derived from Taguchi array
		Cycle Time (Min^s)	0.93	0.36	0.11	
		Rework (%)	20%	18%	15%	
		Percentage of Operatives with experience level	Low 5%	Normal 80%	High 15%	
		Reject (%)	0.12%	0.10%	0.08%	
Extra Personal Check-in Economy	Process Station	Cycle Time	Average 10 Min			Rework for any suspicious passenger derived from Taguchi array
Extra Personal Check First/Business						
High-Risk Process Economy	Process Station	Cycle Time	Average 10 Min			Suspicious passenger derived from Taguchi array
High-Risk Process First/ Business						

Modelling Elements (cont'd)	Model Type	Attribute Value (Variability Levels)				Description
High-Risk Reject Economy **High-Risk Reject First/ Business**	Work Exit Point	Routing Out				Derived from Taguchi array and vary for each experiment
Transfer Passenger	Queue	Queue Size	Infinite			Number of passenger waiting for security Machine
TR Security Machine	Process Station	Active Stations	6	4	1	Derived from Taguchi array and vary for each experiment
		Cycle Time (Mins)	0.93	0.36	0.11	
		Rework (%)	20 %	17.5%	15%	
		Percentage of Operatives with experience level	Low 5%	Normal 80 %	High 15%	
		Reject (%)	0.13%	0.10%	0.07%	
		Daily Demand	6,895	6,140	5,537	
		Weekly Demand	48,267	42,982	38,762	
		Monthly Demand	209,730	186,768	168,429	
Airside Airport Activities	Queue	Queue Size	Infinite			Number of passenger waiting for their flight call
Waiting Boarding Gate open	Queue	Queue Size	Infinite			Number of passenger waiting for boarding desk
Boarding Gate Desk &Take-off	Process Station	Cycle Time	Average 0.1 Min			Assumption as an average process passenger and all flight on time no delay

The following parameters were used to design the simulation (Table 5-3) while Table 5-4 explains the Input Factors or Variables.

Table 5-3 Simulation Parameters

Simulation Parameters	Value
Results Collection Period	Represented the result of end of simulation time and all experiments were undertaken for Day.
Travel Time	Set to Zero, as the model represents a real passenger's flow process and evade the effect of any other factors that may change final results.
Random Time	No randomness as it represents a passenger demand at Abu Dhabi Airport, Terminal 3
Warm Up Time	Set to Zero.
Shift Pattern	0600-1400, 1400-2200, 2200-0600 equivalent to 24hrs per day.
Probability Distribution	Skewed distribution chosen because of the stochastic nature of the inter-arrival time.
Resources	All staff and equipment modelled according to task and shifts.

Table 5-4 Input Factors or Variables in Simulation

Variables/Factor	Properties in Simulation
Batch size (passenger Group size)	Passenger number
	Distribution
Cycle time (Dwell time)	Time
	Distribution
Interval arrival time (Daily Traffic Flow Distribution)	Passenger number
	Distribution
Queue Length Check-in (determines queue taken)	Time
	Capacity
Staffing Capacities	Number of Resources
Aircraft size ,Load factors %	Passenger number
	Distribution
% Experience (level) of Operatives	Level skills
	Distribution
Baggage Problems (All Classes)	% Rework
	Distribution
Assigned Check-in Time	Time
	Distribution
Type of passengers	Passenger labels
	Distribution

Variables/Factor (cont'd)	Properties in Simulation
Passenger Class	Passenger Labels
	Distribution
Has Bags?	Passenger Labels
	Distribution
Number of Processing Stations	fixed in facility and/or brought into operation
	Machine availability
Choice of Supplementary Facilities	Time
	Capacity
Layout of Processing/ Queuing Facilities	fixed in facility and/or brought into operation
Time of Day	Passenger number
	Distribution
Security Statutory check	% Rework
	Distribution
Security High-Risk Warning	% Reject
	Distributions
Emigration (Fatal)	% Reject
	Distribution
Emigration /Visa Issues	% Rework
	Distribution
Check-in (all classes) (Fatal)	% Reject
	Distributions

5.5 Design of Experiments – Taguchi Data

Section 4.6.1 described the next step is to determine the quality characteristic to be optimised, the main functions side effects and failure mode of the process under consideration. This enables identification of factors (parameters) whose variation have critical effect on process quality (Unal and Dean 1990)

In this case, the following Tables (5-5 to 5-14) define the factors used as a basis for designing the matrix experiment for the design and analysis procedures based on controllable factors.

Tables 5-5 to 5-14 factors based on main outcomes of the literature review as defined and presented in chapter 3, tables 3-1 and 3-2. For example table 5-5 factors developed based on table 3-1. The factors reduced based on the required factors of economy-class check station. These factors reflect the activities of the station. These factors have been also verified and confirmed by each station process manager.

The next step following identifying the main factors for each process, data in three levels needs to be established to complete the Taguchi table. The table data constructed in three levels based on quantitative data discussed and obtained from the process managers and the airport data.

These tables needed as part of the objective 1 and used to generate Taguchi arrays to run the simulation.

Tables 5-5 to 5-14 have several factors that influence the departure process flow. The main task of Taguchi is to reduce factors as on target performance of the process which associates a value to process quality by using the loss function. The process quality in this context is meeting passenger satisfaction by reducing waiting time. The factors of the process can be classified as controllable factors and non-controllable factors. Controllable factors are those needs to be optimised such as active station. Uncontrollable factors such as the weather or air traffic controllers' issues. Taguchi develop orthogonal arrays for the controllable factors with setting levels. The orthogonal have properties that serve to reduce the number of experiment needed. Taguchi method aims to develop process design which is insensitive to noise factors, factors which either cannot be controlled or are too expensive to control, and that remain on target with minimum factors. From Tables 5-5 to 5-14 researchers defined which standard orthogonal array was to be used by counting the total degrees of freedom (*dof*). This helps to determine the minimum number of experiments needed to be run to study the effects of the factors involved.

Tables 5-5 to 5-14 have been constructed from three main resources. The first is the airport data database, observation, interviews with departure terminal station manager and direct observation. Table 5-5 shows 10 factors with three levels of economy-class check-in the first factor of the table is active station, number of counter with three levels. Level 1 represent the maximum number of counters, Level 2 is the average number of counters and 3 is the minimum number of opened counter. The second factor represents the cycle time of the process collected from the airport data base with maximum value of 2.76 min, 1.93 min average and minimum 1.56. The reject estimated 5% maximum, 3% average and minimum 1%. Details of the main reasons for rework are shown in Table 5-16. Percentages of the reject estimated as 0.3% maximum, 0.2% average and 0.1% minimum. The percentage of the rework and reject established from work station mangers. Batch size represents group of passengers travelling together and set 8, 3, 1. Each batch size has three levels. Each level contains three percentages related to the batch size. Baggage status factor constructed in three types, with baggage (WB), Hand baggage (HB) and without baggage (NB). The baggage status also has three levels and each level has three set of percentage value reflect the type of baggage. Level 1 represent the maximum, level 2 represents the average and level 3 represent the minimum. Percentages of operatives with experience are in three levels. Highly experience operator has 15%, average experience operator 80% and operator with low skills 5%. The percentages established from the economy-class check-in station managers interview. Daily demand, weekly demand and monthly demand established from the flight schedule database. The three factors are also presented in three levels maximum demand, average and minimum demand. The maximum daily demand 4,944, average demand 4,091 and minimum demand 3,515. The maximum weekly demand 34,606, average demand 28,639 and minimum demand 24,605. The maximum monthly demand 150,370, average demand 128,445 and minimum demand 106,913.

Table 5-5 Economy-Class Check-in - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	8	5	3
Cycle Time (min)	2.76	1.93	1.56
Rework (%)	5%	3%	1%
Reject (%)	0.3%	0.2%	0.1%
Batch Size 8,3,1 (Units)	10%,70%,20%	8%,75%,17%	2%,88%,10%
Baggage Status WB, HB, NB	90%,8%,2%	90%,8%,2%	90%,8%,2%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Daily Demand	4,944	4,091	3,515
Weekly Demand	34,606	28,639	24,605
Monthly Demand	150,370	124,445	106,913

Table 5-6 Economy-Class Emigration - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	8	3	2
Cycle Time (Min)	1.3	0.75	0.55
Rework (%)	0.23%	0.19%	0.15%
Batch Size8,3,1 (Units)	10%,70%,20%	8%,75%,17%	2%,88%,10%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Reject (%)	0.18%	0.15%	0.12%

Table 5-7 Economy-Class Security - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	2	2	1
Cycle Time (Min)	0.93	0.36	0.11
Rework (%)	20%	18%	15%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Reject (%)	0.22%	0.18 %	0.14%

Table 5-8 Economy-Class Transit Passengers Security - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	6	4	1
Cycle Time (Min)	0.93	0.36	0.11
Rework (%)	20 %	17.5%	15%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Reject (%)	0.13%	0.10%	0.07%
Daily Demand	6,895	6,140	5,537
Weekly Demand	48,267	42,982	38,762
Monthly Demand	209,730	186,768	168,429

Table 5-9 Economy-Class Baggage Drop-Off - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	6	5	3
Cycle Time (Min)	2.48	1.65	0.9
Rework (%)	5%	3%	1%
Reject (%)	0.3%	0.2%	0.1%
Batch Size 8,3,1 (Units)	10%,70%,20%	8%,75%,17%	2%,88%,10%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Daily Demand	1,309	1,083	930
Weekly Demand	9,160	7,581	6,513
Monthly Demand	39,804	32,941	28,301

Table 5-10 Economy-Class Self – Check-In - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	12	8	6
Cycle Time (Min)	2.31	1.48	0.65
Daily Demand	582	481	414
Weekly Demand	4,071	3,369	2,895
Monthly Demand	17,691	14,641	12,578
Reject (%)	0.3 %	0.2 %	0.1%

Table 5-11 First-Class Check-In- Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	5	3	1
Cycle Time (Min)	2.76	1.93	1.56
(%) Rework	2%	1%	0.5%
Batch Size8,3,1 (Units)	10%,17%,73%	6%,16%,78%	0%,13%,87%
Baggage Status WB, HB, NB	90%,8%,2%	90%,8%,2%	90%,8%,2%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
(%) Reject	0.15%	0.10%	0.05%
Daily Demand	162	134	115
Weekly Demand	1,131	936	804
Monthly Demand	4,914	4,067	3,494

Table 5-12 Business-Class Check-In - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	8	5	1
Cycle Time (Min)	2.76	1.93	1.56
(%) Rework	3%	2%	1%
(%) Reject	0.2%	0.15%	0.1%
Batch Size8,3,1 (Units)	3%,18%,79%	2%,15%,83%	1%,12%,87%
Baggage Status WB, HB, NB	90%,8%,2%	90%,8%,2%	90%,8%,2%
(%) Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Daily Demand	646	535	459
Weekly Demand	4,524	3,744	3,216
Monthly Demand	19,656	16,267	13,976

Table 5-13 First & Business-Class Emigration - Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	4	2	2
Cycle Time (Min)	1.3	0.75	0.55
(%) Rework	0.12%	0.10%	0.08%
Batch Size8,3,1 (Units)	3%,18%,79%	2%,15%,83%	1%,12%,87%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Reject (%)	0.10%	0.08%	0.06%

Table 5-14 First and Business-Class Security- Taguchi

Factor	Level 1	Level 2	Level 3
Active Stations	1	1	1
Cycle Time (Min)	0.93	0.36	0.11
(%) Rework	20%	18%	15%
Percentage Of Operatives With Experience Level	High (3) 15%	Medium (2) 80%	Low (1) 5%
Reject (%)	0.12%	0.10%	0.08%

5.6 Process Mapping - Linking Data to Simulation Model

5.6.1 Identification of Variables

Some identified variables (Section 3.5) were unsuitable to incorporate in the simulation model either because of local conditions in Abu Dhabi Airport; the specificity of variables to studies in which there were identified; or because the nature of the model described in previous chapters was such that various factors should be combined in practice to avoid excessive and unnecessary complexity in the model. Table 5-15 shows the tasks incorporated in the final version of the model. The nature of each processing station is such that while some variables are common to all processes, each of the chosen variables must be considered in relation to specific processes. Before considering these variables, Table 5-15 provides a list of individual operations or tasks taking place within the process. However, it was beyond the scope of this research to measure each of these tasks in detail or attempt improvement in individual processing stations using Lean principles. Instead, when appropriate and not directly related to flow within the simulation model, each processing station was treated as a 'black-box' with consideration only its inputs and outputs. This eliminated further variables from the list (Section 3.5). Nevertheless, the approach taken in this case resulted in a significantly more detailed simulation model of the entire passenger departure process that those identified in previous studies.

Table 5-15 generated from the stations process mapping that have been shown and explained in figures 5-3 to 5-19. The table shows the passenger journey tasks step by step for each station.

Table 5-15 Simulation Model: List of Tasks by Processing Station

Check-in	**Standard Operator Tasks** • Check if local • Check ticket (passenger documents) • Check passport and visa (passenger documents) • Initial check baggage weight / type of baggage • Check fight manifest (on computer) • Enter passenger information • Check for alerts • Ask legal questions • Ask location and dietary questions • Weigh hold-baggage • Check hand-baggage • Print and Affix labels • Return hand-baggage • Switch hold-baggage to main conveyor • Print boarding card • Return passenger documents with boarding card **Self-Check-in** • Passenger enters details of ticket (passenger documents) • Passenger enters details of passport and visa (passenger documents) • System check fight manifest (on computer) • Passenger enters passenger information • Passenger answers legal questions • Passenger enters location and dietary questions • Entry to terminal • Proceed direct to baggage drop **Pre-Booked Passenger Tasks** • Inspect boarding card • Check passport and visa (passenger documents) • Initial check baggage weight / type of baggage

Table 5-1(cont'd)	• Check for alerts • Ask legal questions • Weigh hold-baggage • Check hand-baggage • Affix labels • Return hand-baggage • Switch hold-baggage to main conveyor • Return passenger documents **Remote Baggage Check-in (with pre-booking)** • Check hand-baggage • Return passenger documents **Standard Operations but Overweight or Special** • Check ticket (passenger documents) • Check passport and visa (passenger documents) • Check fight manifest (on computer) • Initial check baggage weight / type of baggage • Check fight manifest (on computer) • Refer passenger to overweight payment desk / non-standard baggage desk • Check ticket (passenger documents) • Check overweight baggage/unusual item receipt • Check passport and visa (passenger documents) • Check fight manifest (on computer) • Enter passenger information • Check for alerts • Ask legal questions • Ask location and dietary questions • Weigh hold-baggage • Check hand-baggage • Affix labels • Return hand-baggage • Switch hold-baggage to main conveyor • Print boarding card • Return passenger documents with boarding card *NOTE Different procedure for First-Class passengers with Overweight or Special Item Baggage* **First-Class Operations but Overweight or Special Baggage** • Check ticket (passenger documents) • Check passport and visa (passenger documents) • Check fight manifest (on computer) • Initial check baggage weight / type of baggage • Summon baggage handler • Check passport and visa (passenger documents) • Check for alerts • Ask legal questions • Ask location and dietary questions • Weigh hold-baggage • Check hand-baggage

	• Affix labels • Return hand-baggage • Switch hold-baggage to main conveyor • Print boarding card • Return passenger documents with boarding card
Table 5-15(cont'd) **Emigration**	**Standard Passenger** • Visual check boarding card • Visual check passport • Visual check visa • Verify identity of passenger • Scan boarding card • Scan passport • Check alerts • Ask supplementary questions • Return boarding card and passport **Pre-Alert for Passenger** • Visual check boarding card • Visual check passport • Visual check visa • Verify identity of passenger • Scan boarding card • Scan passport • Check alerts • Further investigations • Summon duty officer (if appropriate) • Interview passenger • Verify position with duty manager • Detain or turn back passenger • Or return boarding card and passport
Security	**Standard Passenger (80%)** • Receive prohibited items • Issue bag for liquids and other hi-risk items • Inspect boarding card & passport • Receive pocket contents in container/tray • Instruct passenger on removable items (shoes/belts • Receive hand-baggage • X-ray scan container and hand luggage • Visually inspect bag of hi-risk items • Visually check passenger (body language etc.) • Direct passenger through induction arch • If alert sounds further instructions or wand check of passenger **Standard Passenger (20%** Random Check – International Legal Requirement and **Medium High-Risk Passengers)** • Receive prohibited items • Issue bag for liquids and other hi-risk items • Inspect boarding card & passport

<table>
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<td>Table 5-15(cont'd)

Boarding Gate</td>
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Receive pocket contents in container/tray
Instruct passenger on removable items (shoes/belts
Receive hand-baggage
X-ray scan container and hand luggage
Visually inspect bag of hi-risk items
Direct passenger through induction arch
If alert sounds further instructions
Re-direct passenger to inspection area or separate female inspection area
Visually check passenger (body language etc.)
Pat down and hard search
Wand search

High-Risk Passengers
NOTE: Passenger may be observed and detained before reaching normal security area otherwise

Receive prohibited items
Issue bag for liquids and other hi-risk items
Inspect Boarding Card & Passport
Re-direct Passenger to Holding Area
Collect and Bag Personal Items
Summon Duty officer
Escort to special inspection area
Questioning or Inspection Procedure (varies with type of risk)
Detain Passenger in Secure Room (if appropriate)
Summon Police/Security Services
Hand over
OR (if appropriate) release back to general security area THEN

Receive prohibited items
Re-issue bag for liquids and other hi-risk items
Receive pocket contents in container/tray
Instruct passenger on removable items (shoes/belts etc)
Receive hand-baggage
X-ray scan container and hand luggage
Visually inspect bag of hi-risk items
Direct passenger through induction arch
If alert sounds further instructions
Re-direct passenger to inspection area or separate female inspection area
Visually check passenger (body language etc.)
Pat down and hard search
Wand search

All Economy and Business-Class Passengers

Summon Passengers to Boarding Area (30 minutes ahead of (re)scheduled departure
Visually check passenger (body language etc.)
Open Boarding Gate
Call Passengers in batches to Boarding Gate
Inspect Boarding Card
Check off passengers against manifest
Retain and file detachable portion of boarding card

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Table 5-15(cont'd)	• Count boarding cards and verify against manifest • Issue new call for any absent passengers • Visually check late passenger (body language etc.) • Inspect Boarding Card • Check off late passengers against manifest • Retain and file detachable portion of boarding card • Count boarding cards and verify against manifest • Issue last call for any absent passengers • Visually check late passenger (body language etc.) • Inspect Boarding Card • Check off late passengers against manifest • Retain and file detachable portion of boarding card • Count boarding cards and verify against manifest • Issue last call for any absent passengers • Visually check late passenger (body language etc.) • Inspect Boarding Card • Check off late passengers against manifest • Retain and file detachable portion of boarding card • Count boarding cards and verify against manifest • Notify captain of aircraft of any missing passenger or • Close boarding gate

5.6.2 Equating Airport Variables with the Lean Philosophy

A further problem concerned differences in terminology between the current application of Lean and the original Lean philosophy. Lean's origin in manufacturing means that for clarity of understanding and incorporating into the simulation model, certain terms used in airport operations were matched with those used in manufacturing. Table 5-16 overleaf shows how manufacturing terms and airport operations are equated. The manufacture terms that have been used in normal manufacturing process have been explained from the airport operation context. The explanation of each term derived from the interviews with station managers and the direct observation of the process by the researcher. For example rework can be baggage overweight. The check-in counter will ask the passenger to solve over baggage, i.e. the baggage is over the permitted weight. In this case the passenger either pays the penalty or reduces the weight of the baggage. The passengers will be taking a rework process of the check-in station process. Reject example in classes includes problem with the ticket such as the ticket invalid or the passenger date of flight different from the one stated in the ticket. Valid visa for the passenger destination needs to be valid and approved. Without appropriate and valid visa the passenger will be rejected from the process.

Table 5-16 Translation of Airport Conditions into Lean/Manufacturing Terms

Normal Manufacturing Term	Airport Departure Process	Airport Operation
Rework	Check-in (all classes)	Baggage problems such as overweight, unusual items, oversized items, problem contents etc.
Reject	Check-in (all classes)	'Fatal' problems with tickets, passports, visas etc which result in passengers not being allowed to fly or proceed past this stage.
Reject	Check-in	Passenger has outstanding debt problems or other issues which contravene Abu Dhabi/UAE national laws and prohibit flying unless resolved.
Rework	Emigration	Visa issues, problems with passports and other documents etc.
Rework	Emigration	Security issues; low and medium immigration risk warnings (national and international);
Reject	Emigration	'Fatal' errors with visas, passports and other documents such as producing fake passport and documents.
Rework	Security	Statutory checks on stipulated percentage of all passengers. Passengers with high-risk warnings when returned to the immigration queue after extensive checks are also taking to be rework.
Reject	Security	High-risk warnings which result in passenger not being allowed to fly or proceed past this stage.

5.6.3 Standard Conditions in Departure Process

Tables 5-17 to 5-27 are the result of applying a rule-based default rule to individual parts of the process in the original (unimproved) simulation model designed in accordance with the designs shown in Section 5.5.1 of the previous Chapter.

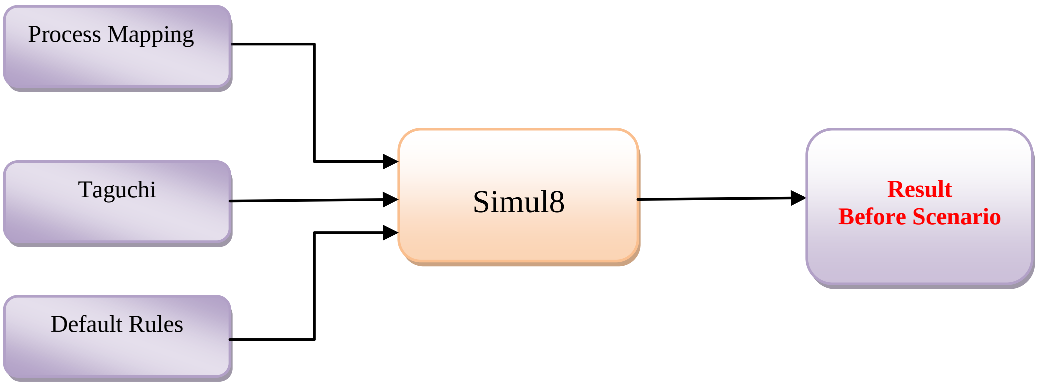

Figure 5-19 Simulation model flow chart before scenario

CHECK-IN

Table 5-17 shows the simulation rules for standard economy-class check-in process. At a given instance, 3 check-in processing stations are permanently active. However, based on the queue length more countered can be opened (max number of processing station are 8) and passengers can diverted. The physical queue length (pax) is 150 i.e. the maximum number of passengers the queue can hold, queuing capacity. The check in queue type is Disney, the physical shape of the passenger queue line. The table also indicated passengers queue lengths of four scenarios; queue lengthy >=100 pax and queue length >=150 pax. The rules for queue length >=100 pax includes check processing station optimised i.e. 8 open stations all highly skilled operators. Or the rule for passenger who cannot go to CIEDB until they have been checked in so staff to assist CIE by creating single queue to help passengers check-in then re-direct to CIEDB. The table can be linked to figure 5-9, process mapping of check-in process. The figure indicates the bath that needs to be taken based on the rules stated in table 5-17.

Table 5-17 Simulation Rules: Standard Economy-Class Check-in

Process Station	Conditions			
Standard Check-in Economy (CIE)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	3	8	150	Disney
Rules				
a. Queue Length >=100pax	Check processing stations optimised i.e. 8 open stations all highly-skilled operators *NB time for changeover – changeover should be complete by next trigger (>150) reached.*			
b. Queue Length >=100pax	*People cannot go to CIEDB until they have been checked in* so Staff to assist CIE by creating side queue to help passengers check-in then re-direct to CIEDB			
c. Queue Length >=150 pax	Divert people to self-check-in			
d. Queue Length >150 pax	Then Active Station =8 Check-in with highly-skilled operators			

Table 5-18 Simulation Rules: Economy-Class Self-Check-in

Process Station	Conditions			
Self-Check-in Economy(CIES)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	6	12	(say) 100	Disney
Rules				
a. Queue Length >=100 pax	When queue length >100 divert people to Economy Drop-Baggage (CIEBD)			

Table 5-19 Simulation Rules: Economy-Class Baggage Drop

Process Station	Conditions			
Check-in Baggage Drop Economy (CIEBD)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	5	6	100	Disney
Rules				
a.	Default settings			

Table 5-20 Simulation Rules: Business-Class Standard Check-in

Process Station	Conditions			
Standard Check-in Business-Class (CIBC)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	5	8	8 x 10	Individual
Rules				
a.	Default settings			

Table 5-21 Simulation Rules: Business-Class Self Check-in

Process Station	Conditions			
Self-Check-in Business-Class (CIBCS)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	4	4	4 x 5	Individual
Rules				
a.	Default settings			

Table 5-22 Simulation Rules: First-Class Standard Check-in

Process Station	Conditions			
First-Class Standard Check-in (CIFC)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	3	3 (5)	3 x 10	Individual
Rules				
a.	Default settings			

EMIGRATION

Table 5-23 Simulation Rules: Economy-Class Emigration

Process Station	Conditions			
Emigration Economy (EE)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	2	8	8 x 10	Disney
Rules				
a.	Default settings			

Table 5-24 Simulation Rules: First/Business-Class Emigration

Process Station	Conditions			
Emigration First/Business-Class (EFB)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	2	4	4 x 10	Disney
Rules				
a.	Default settings			

SECURITY

Table 5-25 Simulation Rules: Economy-Class Security

Process Station	Conditions			
Security Economy (SE)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	2	*+1 from First/Business*	3 x 10	Disney
Rules				
a.	Default settings			

Table 5-26 Simulation Rules: Transfer Passenger Security

Process Station	Conditions			
Security Transfer Passengers (STP)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	4	6	100	Disney
Rules				
a.	Default settings			

Table 5-27 Simulation Rules: First/Business-Class Security

Process Station	Conditions			
Security First/Business-Class (SFB)	**Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
	1	*+2 Economy*	3 x 10	Disney
Rules				
a.	Default settings			

Boarding Desk (all classes) - No need to join and share stations

5.7 Chapter Summary

This Chapter examined methods of data collection and use of the triangular methodology and how the validity and reliability of data would be achieved. Each of these was developed into a series of research methods steps. The Chapter also examined the question of process of simulating the passenger departure process and the potential role of simulation in the overall research process. Taguchi methods were proposed and the Chapter next set out the parameter design including Taguchi levels for each of the processing stations.

Finally, the Chapter examined how and why ANOVA and regression analysis form an important step when considering results and improving various parts of the process.

Chapter 6 : Presentation of Results

6.1 Overview

This Chapter presents the results of data collection which took place in Abu Dhabi Airport, Terminal 3, partial analysis of these data preparatory to constructing and analysing simulation models, and the results of simulation.

6.2 Empirical Data Description

The sensitive nature of detailed data for airport operations compelled the Abu Dhabi Airports Authority and Abu Dhabi State Security Services to make field data collection the subject of a formal non-disclosure agreement. Accordingly collected data is provided only in a series of access-limited tables in Confidential Appendixes (Appendixes B). These are identified as necessary within the text. Supplementary data and information is held in confidential files under similar security restrictions. In consequence, the main body of this thesis excludes specific references to numbers of patterns of passenger flow which are now contained within Confidential Appendixes.

6.2.1 Important Differences from Manufacturing Processes

Several important differences are apparent when considering the empirical data, if one compares it to data which normally occurs in manufacturing processes and which makes the airport departure process is fundamentally different from normal Lean models. Although some of these differences were discussed in more detail in earlier chapters it is nevertheless appropriate to summarise the ten most important differences when considering the data presented in this Chapter:

1. Passengers are not inert components in a process but are rather thinking entities who may not always behave entirely as process designers conceive because they act in their own immediate interest or from unfamiliarity with the airport environment;
2. The individual elements of the passenger departure process at processing stations is not the responsibility of a single entity, but of several separately managed entities although the Airport Authority provides coordination;
3. The passenger departure process begins as a ‘push’ system and as the process later becomes a ‘pull’ system immediately before the departure gate;

4. Actual departure time, which provides the only ‘pull’ in the departure process is uncertain, normally due to factors outside the Airport Authority’s control. Delays to actual departure may be significant at times (Appendix B 3).
5. Viewed over different periods (seasonally, monthly, weekly and daily) the departure process is the subject of peaks and troughs in demand which may be cumulative (Figure 6-1) and which may occur several times during each of these periods. Peaks and troughs are generally measured by airports in terms of aircraft departures. This may be misleading when one considers the lead between different elements (i.e. processing stations) of the process. Thus for example, earliest call to check-in may be some four hours ahead of scheduled departure time creating different peak periods in each processing station;

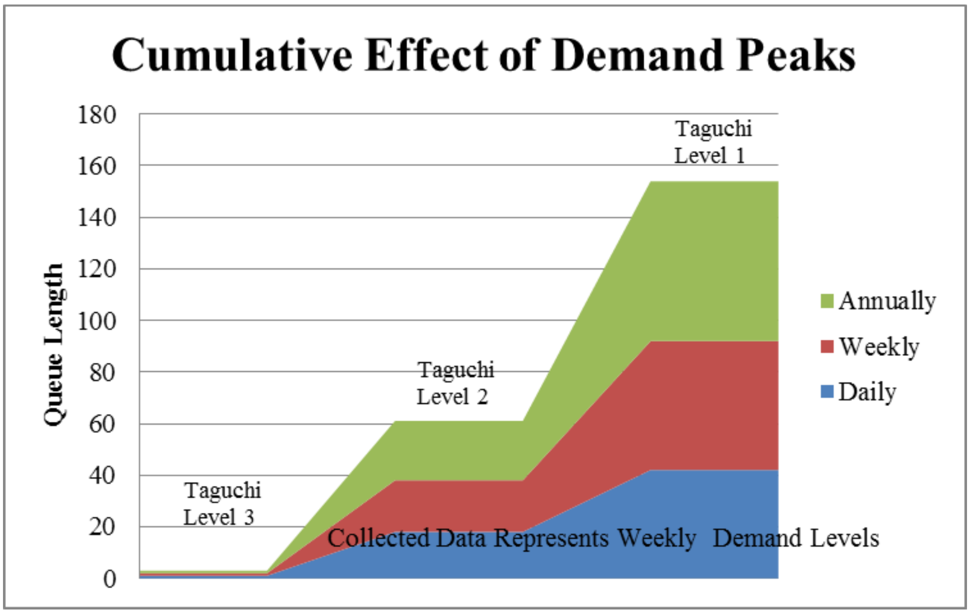

Figure 6-1 Demand Peaks Combined

6. Although the ‘passenger arrival process’ is not the subject of this research study, it was noted that peak aircraft arrival times differ from peak departures. Lags occur after touchdown for different elements of the process. The difference between peak arrivals and peak departures and their associated processes, which frequently use the same personnel may provide further improvements to human resource usage;
7. Passenger types may vary considerably from one type of flight to another depending on destination and peak flow of various types. For example, the person-by-person and group composition of seasonal passengers attending the

Hajj in Mecca, will be different from long-distance flights to predominantly business destinations, which will in turn be different from flights which run to short and long haul holiday destinations. It was outside the scope of this study to consider these differences;

8. Individual processes may vary, sometimes at short notice or unpredictably because of external events, many of which may occur hundreds or thousands of miles away from the immediate airport environment as well as locally;
9. The strong regulatory and security environment which surrounds air travel overrides any consideration of process improvements. These also may change at short notice in reaction to external events anywhere in the world;
10. For economic reasons, the objective of airport authorities is not to reduce overall throughput time during the departure process, but to free passengers from attendance at individual processing stations to give them more time in concessionary areas. Some observers may see this as being directly contrary to Lean principles, though most airport authorities regard this necessary part of their economic model.

6.3 Simulation Model Results: Discrete Processes

Using the field data contained in detail in Confidential Appendix B4 and the parameter designs of control factors described in Tables 5-5 to 5-14, data were imported into Minitab. This program contains specific functions for orthogonal arrays which use control factors for the in the inner array and noise factors for the outer array. The control factors are those factors, which are potentially controllable to optimise the process whereas noise factors can affect the performance of the system which is not in control. The graphic output of Minitab which resulted from these calculations is shown in Figures 6-2 to 6-55 and their interpretation is shown when necessary in the same subsection in which results are displayed. To avoid unnecessary duplication of description the following must be noted:

1. When the line is horizontal and parallel to the x-axis there is no main effect present and the response mean is the same across all factor levels. For example, Figure 6-2, passenger size does not have effect on throughput.
2. When the line is not horizontal, a main effect is present because the response mean is not the same across all factor levels. The greater the steepness of the line, the greater the magnitude of the main effect. For example, Figure 6-2, number of active stations has effect on throughput as changing number of active stations from 3, 5 and 8 changes throughput from 280*3, 275*5 and 210*8 respectively.

Based on the Lean principle, simulation model results help to understand and create value from both airport authorities and customer (passenger) perspective. End-to-end value needs to be created i.e. improving the throughput for check-in process will add waste in the process as passengers will start queuing up in front of emigration and security. This will increase the waste in process instead of reducing it. Therefore, analysis from Figure 6-2 to 6-55, allows understanding the effect of variability on PDP flow as a whole process instead of a single processing station.

6.3.1 Check-in

The results obtained from Simul8 are processed and manually inputted to Minitab to generate the main effects plot. The graphical output of Minitab® was used to plot the signal-to-noise effects of the simulation output. However, such output cannot be interpreted in isolation. Instead one must interpret this output only with other methods such as of analysis of variance ANOVA and Multi-Factor analysis of variance (MANOVA). MANOVA can be defined as a one-way Analysis of Variance similar to ANOVA except that there are more than on factors involved in the analysis. This technique is appropriate in research analysis where more than one factors exist influencing the dependant variable.

These are used to test for significant differences between means which involves finding new relations between variables and analysing the differences between group means of the variation among and between groups. In each case the design of the Taguchi array led to a sample size of twenty-seven. The statistical programme Stata® was used to analyse variances using an extension of two-way ANOVA to understand the interaction effect between three or more independent variables (factors) and a continuous dependent variable. This method of analysis is normally referred to as "factorial ANOVA". Factorial ANOVA was chosen in preference to MANOVA because the use of Minitab to analyse signal-to-noise ratio negates the need for other statistical post-estimation techniques normally applied when either analysis method is selected. Whether ANOVA or MANOVA is chosen six assumptions underpin the use of these methods:

1. The dependent variable is measured at continuous level;
2. Each of the independent variables (factors) must consist of two or more categorical, variables from unrelated groups. In this case, Taguchi factors were generally presented as 1, 2, and 3 to satisfy this requirement in the Table of variables;
3. There is independence of observations for each of the factors;
4. There are no significant outliers in these data;
5. The dependent variable is approximately normally distributed for each combination of groups of factors;
6. There is homogeneity of variances for each combination of groups of independent variables. In this case, these assumptions were tested using Levene's test for homogeneity which is also available in Stata®

Consequently, data were prepared to accommodate these needs in ten Stata® datasets (Table 6-1). Datasets are contained in the Confidential Appendix numbered B 5 to B 14. Do-files which describe actions taken in Stata® are also listed and are contained in the General Appendix. A further file which describes variables and their labels are contained in the Confidential Appendix B.

Table 6-1 Location of Additional Data Relevant to Each Processing Station

Table Nr.	File	Description	Appendix Numbers.	
			data file	do file
1	CIE	Economy check-in	B 5	A1
2	CIEDB	Economy drop-baggage check-in	B 6	A2
3	CIES	Economy self-check-in	B 7	A3
4	CIBC	Business-class check-in	B 8	A4
5	CIFC	First-class check-in	B 9	A5
6	EE	Economy Emigration	B 10	A6
7	EFB	First and Business-Class emigration	B 11	A7
8	SE	Economy security	B 12	A8
9	SFB	First and Business-Class security	B 13	A9
10	STR	Transfer passenger security	B 14	A10

Although analyses of the departure gate and boarding gate were carried out, the nature of these operations meant that to accurately analyse flow and divided movements among individual aircraft. This was beyond the scope of this project and consequently only general results were produced as if flow was to a combined waiting area buffer.

6.3.1.2 Economy-Class Standard Check-in

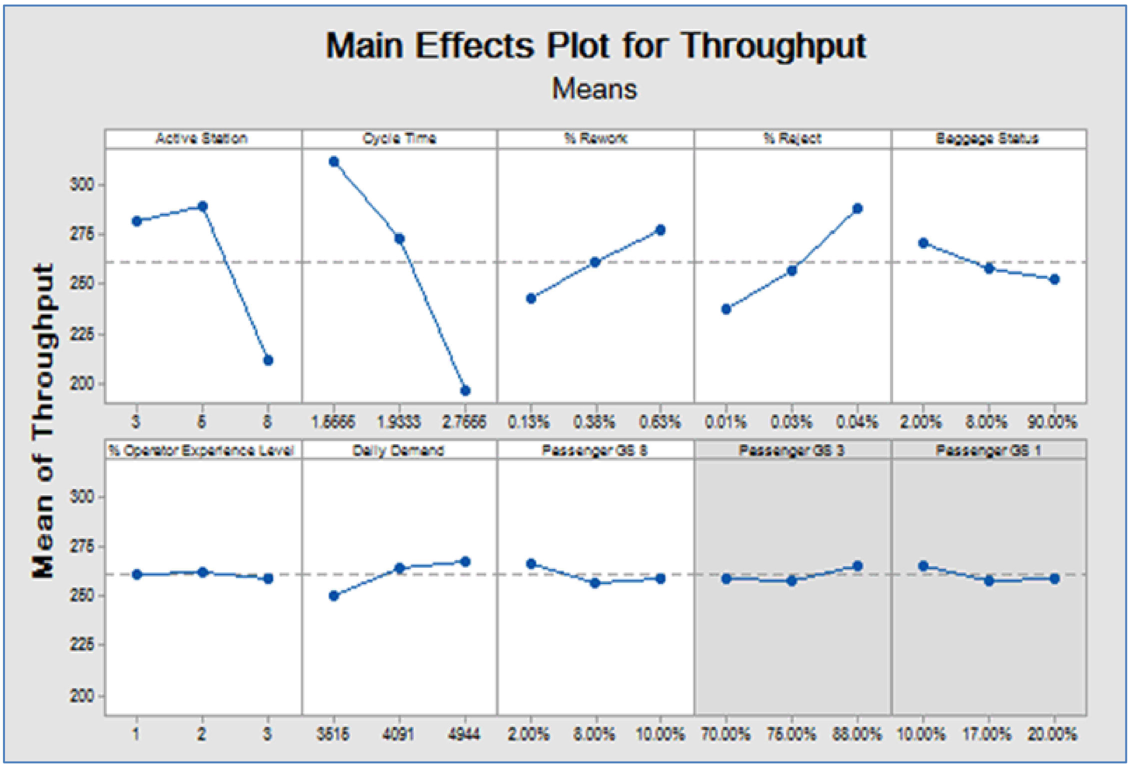

Figure 6-2 Main Effects Plot: Throughput - Economy-Class Standard Check-in

A 10-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-2 to 6-7. Dependent variables were;

1. 'Throughput',
2. 'Average [Mean] Queuing-Time',
3. 'Maximum Queue Size',
4. 'Percentage of [processing station] Working [time]',
5. 'Percentage of [processing station] Waiting [time]', and
6. 'Current Contents [of pre-processing buffer] or WIP.

General Appendixes A11 show the complete results of ANOVA analysis. Non-statistically significant variables are not generally reported in the body of this thesis. To better understand the results, the term '*highly* statistically significant' is used when P< 0.001 followed by '*very* statistically significant' P < 0.01 and then 'statistically significant' for P <0.05. To make interpretation clearer and avoid repetition, Dependent

Variables and their abbreviations are bolded in the text and factor [or independent] variable enclosed in single quotes.

ANOVA results demonstrate the model itself is *highly* statistically significant, F(16,26) = 2.0715, p ≈ 0.000 as it was in all six cases tested where p varied between 0.0000 to 0.0004. In every case, interactions between the dependent variable and [the number of] 'Active Stations', F(2,26) = 3.369, p = 0 were *highly* statistically significant. Except for 'Maximum Queue Size' (Figure 6-6) where the interaction was *very* statistically significant F(2,26) = 3.369, p = 0.0056, interactions between dependent variables and 'cycle time' [of processing station] are *highly* statistically significant F(2,26) = 3.369, p ≈ 0 with p varying between 0.0000 to 0.0031.

Additional statistically significant interactions with dependent variable **throughput** (TP) (Figure 6-2) are with '% [of] Rejects', F(2,26) = 3.369, p = 0.004 which is *highly* statistically significant, and % [of] Rework', F(2,26) = 3.369, p = 0.0339 which is statistically significant.

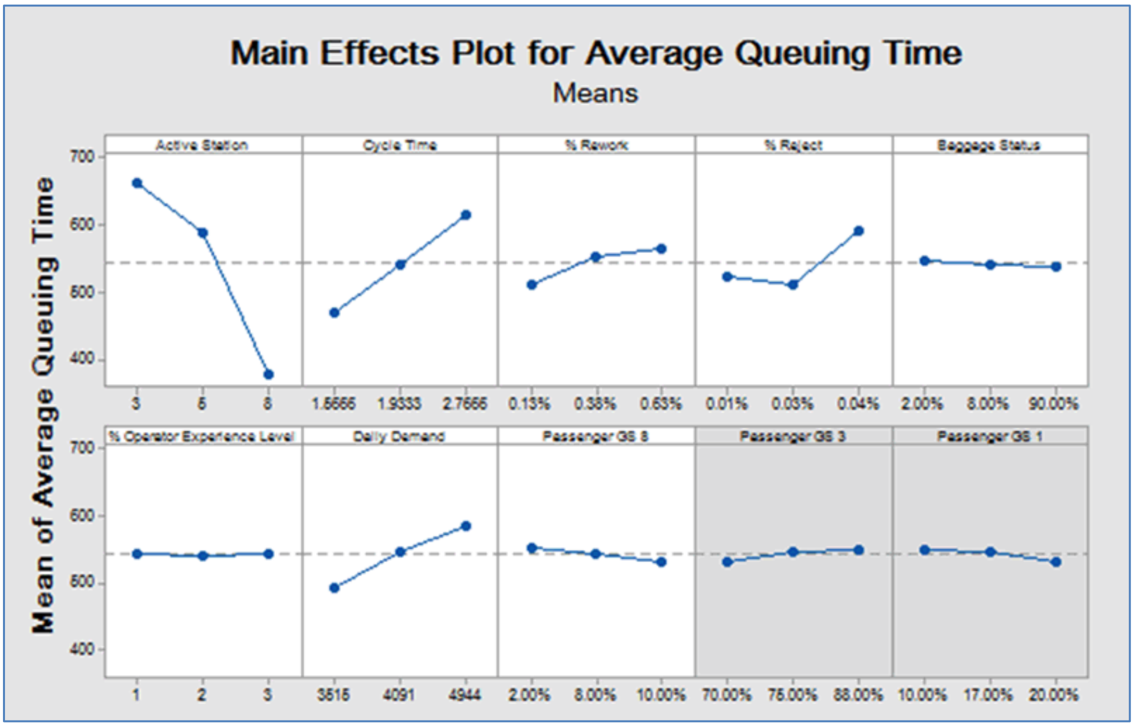

Figure 6-3 Main Effects Plot: Average Queuing-Time - Economy-Class Standard Check-in

Additional interactions between **Average Queuing-Time** (AQT) (Figure 6-3), 'Daily Demand', F(2,26) = 3.369, p = 0.0091 and '% Rejects' F(2,26) = 3.369, p = 0.0091 were both *very* statistically significant. Interaction between **AQT** and '% Rework F(2,26) = 3.369, p = 0.0745 is statistically significant.

In Figure 6-4, an additional interaction between **Maximum Queue Size** (MQS) and 'Daily Demand', F (2,26) = 3.369, p = 0 was *highly* statistically significant, while the interaction between **MQS** and [the number of larger group sizes] 'gs8', F(2,26) = 3.369, p = 0.0264 was statistically significant.

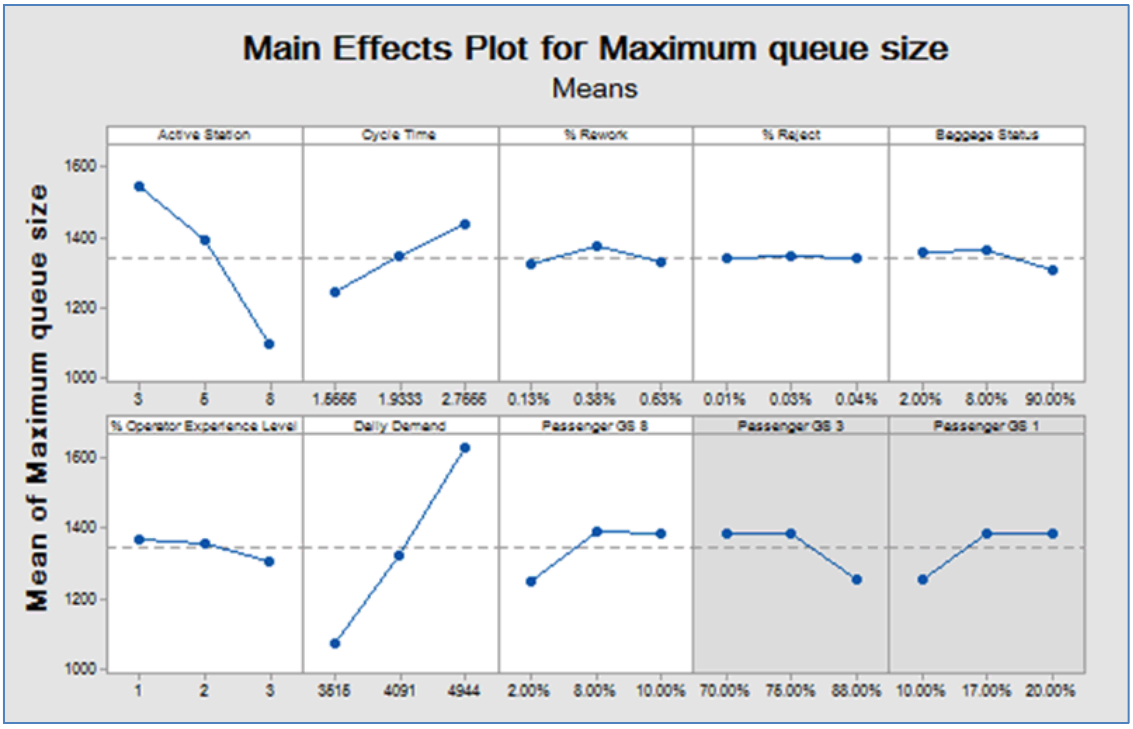

Figure 6-4 Main Effects Plot: MQS - Economy-Class Standard Check-in

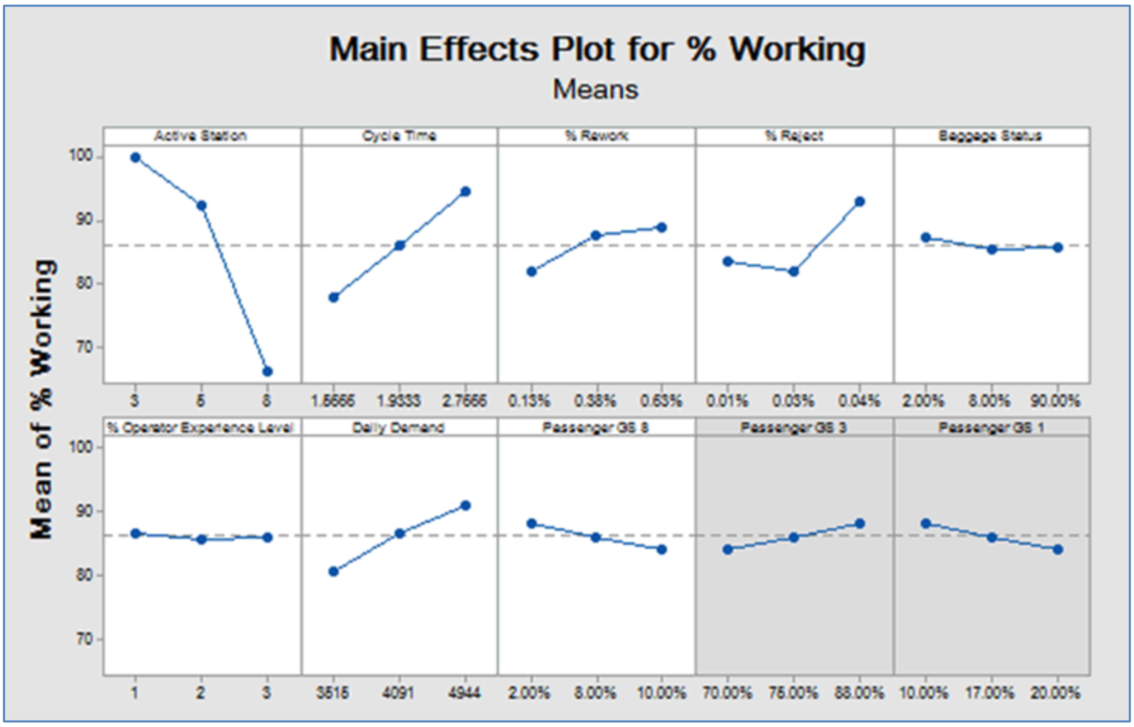

Figure 6-5 Main Effects Plot: Percentage Working Time - Economy-Class Standard Check-in

In Figure 6-5, an additional interaction between **%** [of processing station] **Working Time** (%Wo) and % [of processing station] **Waiting Time** (%Wa) (Figure 6-6)was with '% Rejects', $F(2,26) = 3.369$, $p = 0.0083$ is *very* statistically significant, while the further interactions between **%Wo&%Wa** and 'Daily Demand', $F(2,26) = 3.369$, $p = 0.0266$ are both statistically significant.

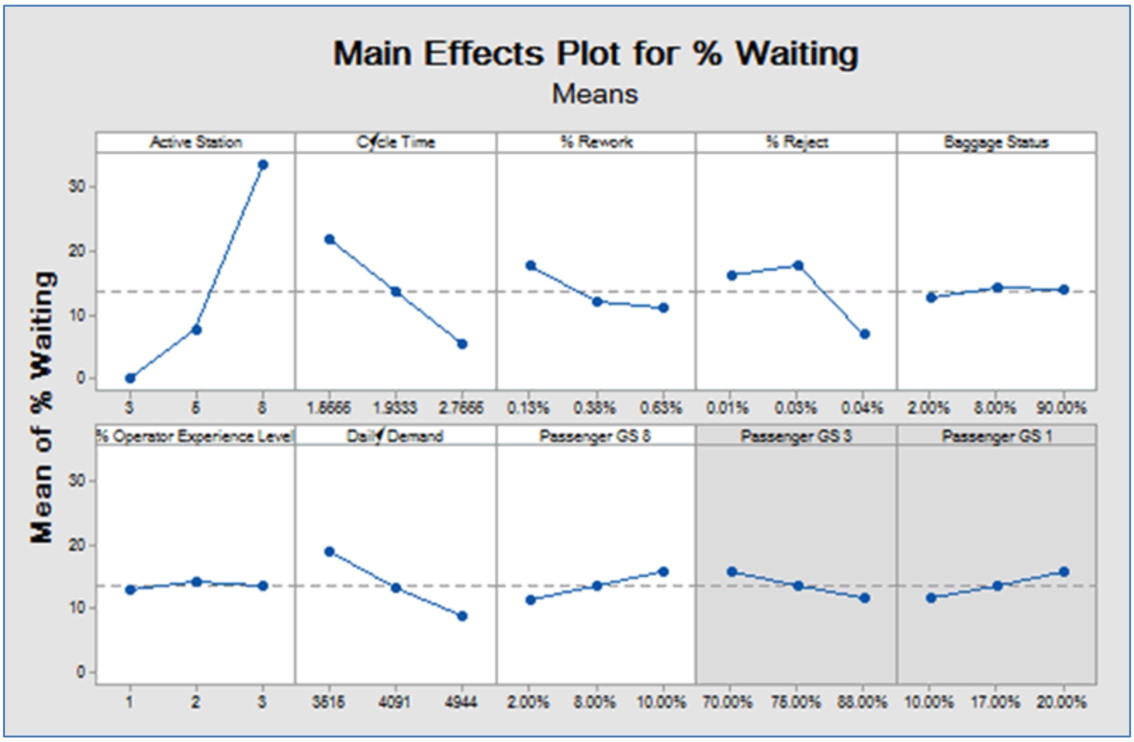

Figure 6-6 Main Effects Plot: Percentage Waiting Time - Economy-Class Standard Check-in

In Figure 6-7, an additional interaction between **WIP** with ‘Daily Demand’, $F(2,26) = 3.369$, $p = 0.0062$ is *very* statistically significant while the further interaction between **WIP** and ‘% Rejects’, $F(2,26) = 3.369$, $p = 0.0563$, is statistically significant.

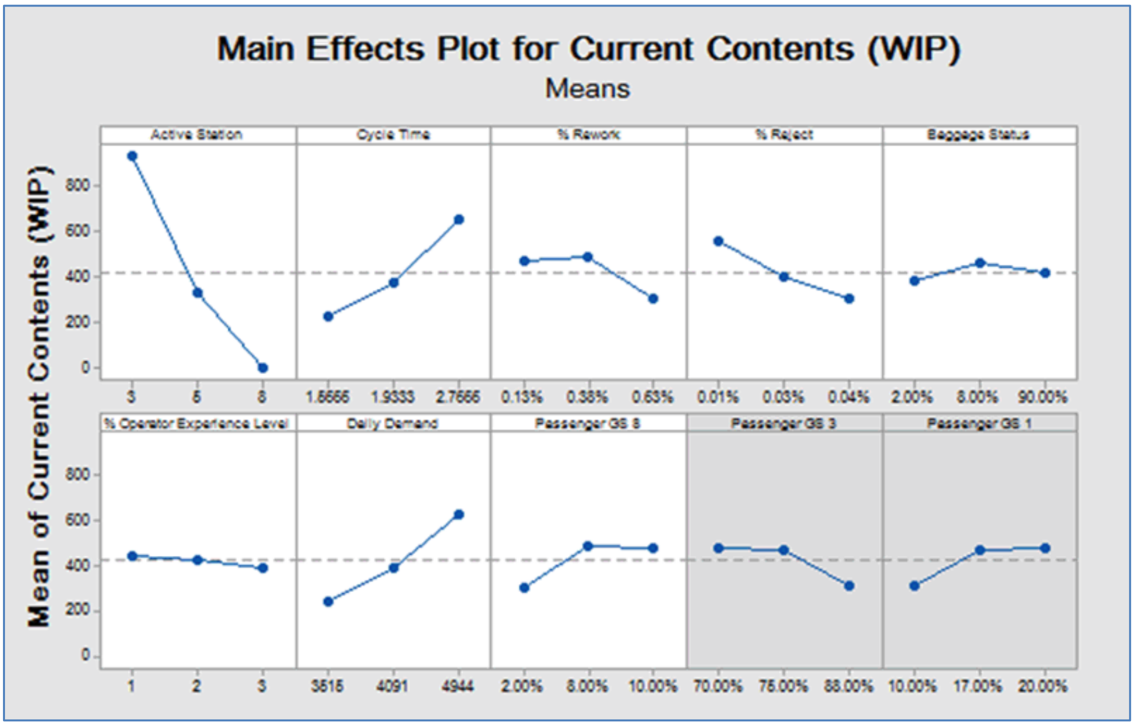

Figure 6-7 Main Effects Plot: WIP - Economy-Class Standard Check-in

6.3.1.2 Economy-Class Self-Check-in

A 4-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-8 to 6-10. Dependent variables were ‘throughput’, ‘Percentage of Working’ and ‘Percentage of Waiting’.

ANOVA results demonstrate the model itself is highly statistically significant, $F(8,26) = 2.3205$, $p = 0$. In every case in this group, interactions between dependent variable(s) and ‘Active Stations’, $F(2,26) = 3.369$, $p = 0$ are *highly* statistically significant.

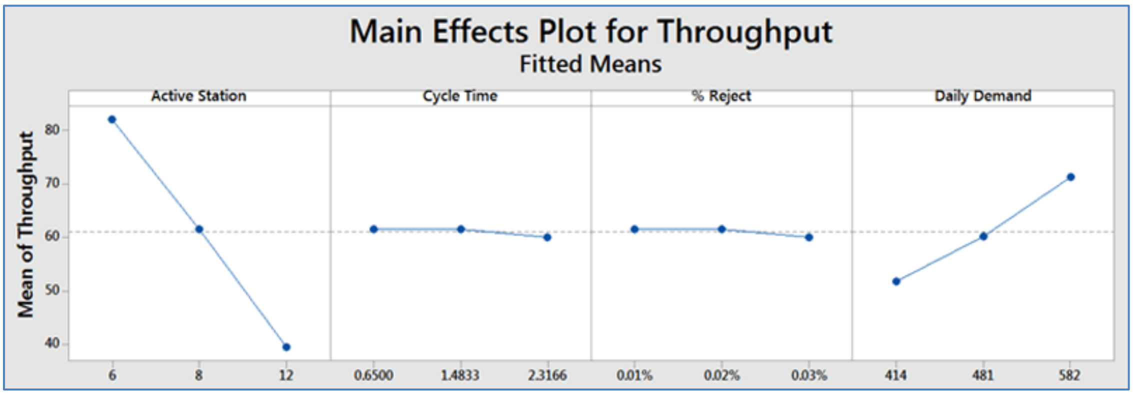

Figure 6-8 Main Effects Plot: Throughput - Economy-Class Self-Check-in

The additional interaction between **throughput** (Figure 6-8) and 'Daily Demand', $F(2,26) = 3.369$, $p = 0$ is *highly* statistically significant.

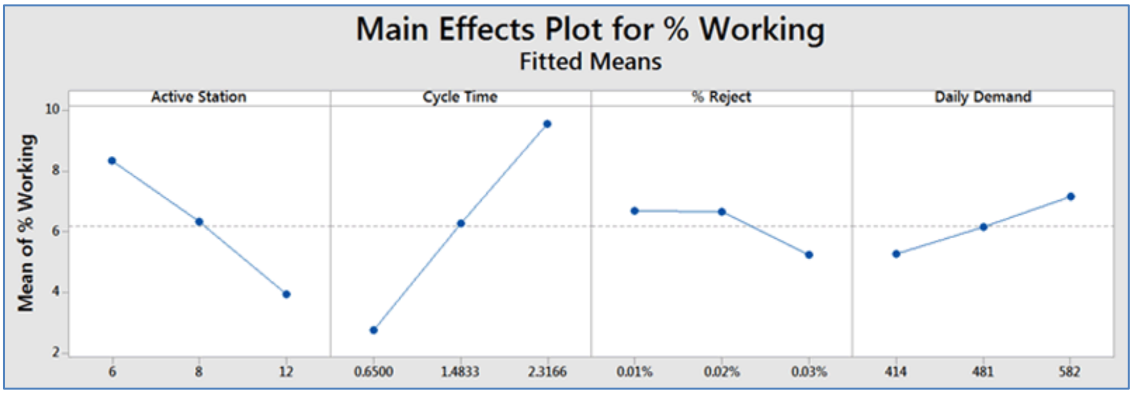

Figure 6-9 Main Effects Plot: Percentage Working Time - Economy-Class Self-Check-in

For **% Working**(%Wo) (Figure 6-9) and **% Waiting**(%Wa) (Figure 6-10) of the processing station the additional interaction with cycle time $F(2,26) = 3.369$, $p = 0$ is *highly* statistically significant. Further interactions between **%Wo&%Wa** and '% Rejects', $F(2,26) = 3.369$, $p = 0.013$ and 'Daily Demand', $F(2,26) = 3.369$, $p = 0.0046$ are *very* statistically significant.

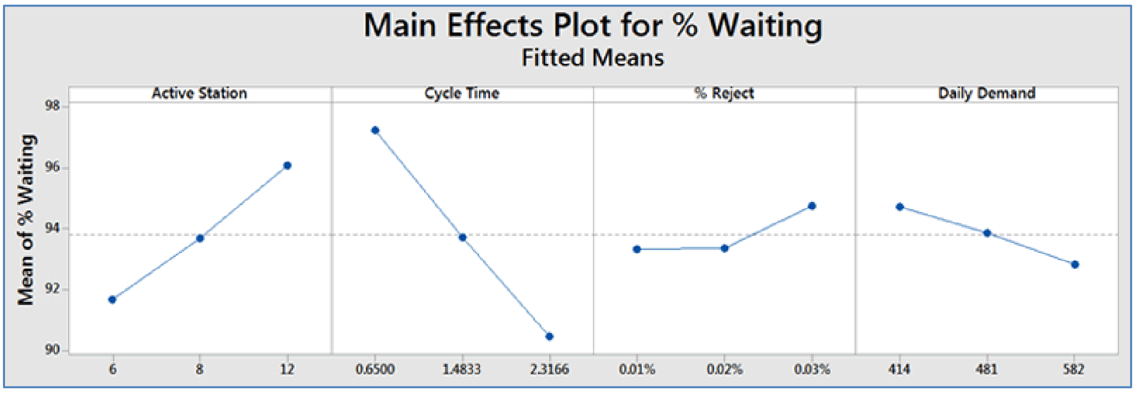

Figure 6-10 Main Effects Plot: Percentage Waiting Time - Economy-Class Self-Check-in

6.3.1.3 Economy-Class Check-in Bag Drop

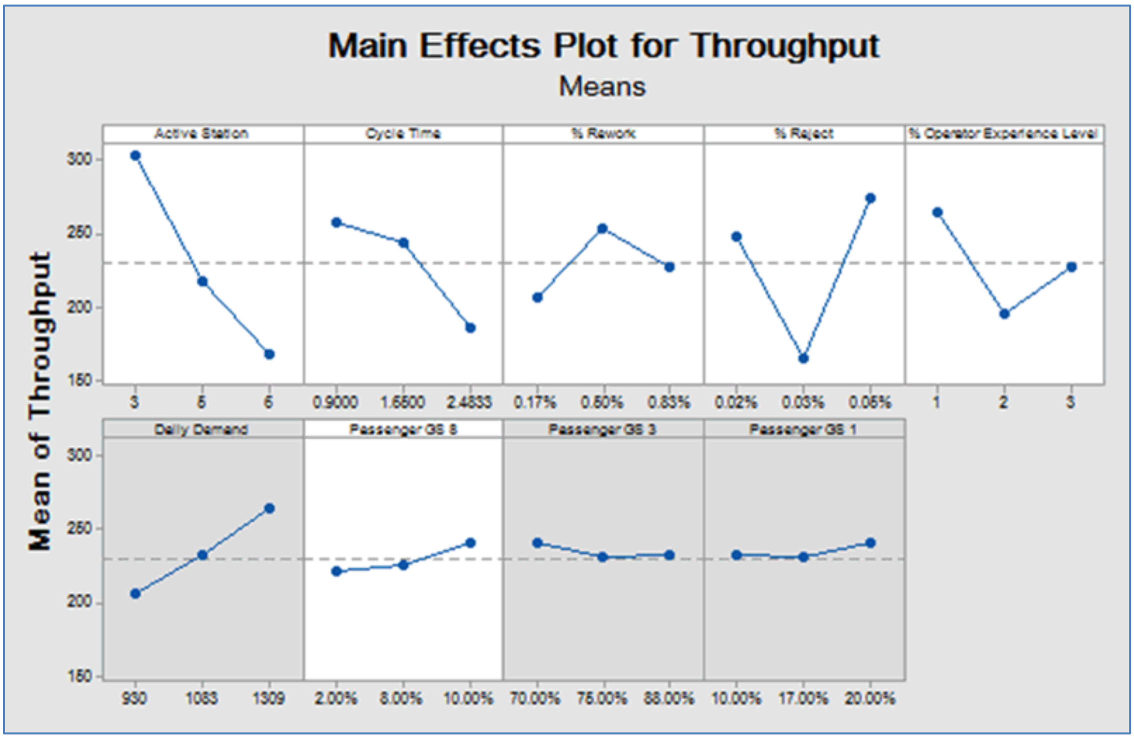

Figure 6-11 Main Effects Plot: Throughput - Economy-Class Bag Drop

A 9-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-11 to 6-16. Dependent variables were ‘throughput’, ‘AQT’, ‘MQS’, ‘Percentage of Working’, ‘Percentage of Waiting’, and ‘WIP’

ANOVA results demonstrate the model itself is *highly* statistically significant, $F(13,26) = 2.1479$, $p = 0$. In every case interactions between the dependent variable and ‘Active

Stations', F(2,26) = 3.369, p ≈ 0 and 'cycle time' F(2,26) = 3.369, p ≈ 0 are *highly* statistically significant with p-values varying between 0.0000 - 0.0029.

In the first model (Figure 6-11) interactions between **throughput** and factors '% Rework', F(2,26) = 3.369, p = 0.0009; % of Rejects, F(2,26) = 3.369, p = 0.0009 and 'Operational Experience', F(2,26) = 3.369, p = 0.0002 are all *highly* statistically significant.

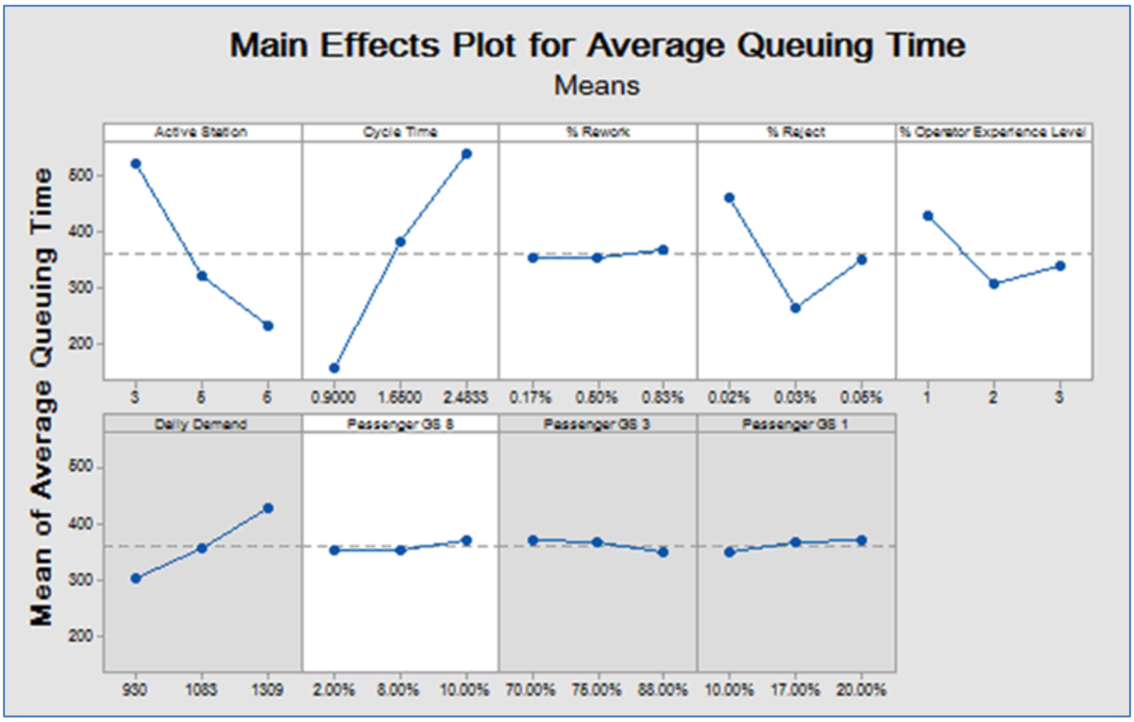

Figure 6-12 Main Effects Plot: AQT - Economy-Class Bag Drop

For **AQT** (Figure 6-12), the additional interaction with '% Rejects', F(2,26) = 3.369, p = 0.0012 and 'Operator Experience' F(2,26) = 3.369, p = 0 are both *highly* statistically significant. Further interactions between **AQT** and 'Daily Demand', F(2,26) = 3.369, p = 0.0541 is statistically significant.

For **MQS** (Figure 6-13), the additional interactions with 'Operator Experience', F(2,26) = 3.369, p = 0, and between **MQS** and 'Daily Demand', F(2,26) = 3.369, p = 0 are both highly statistically significant.

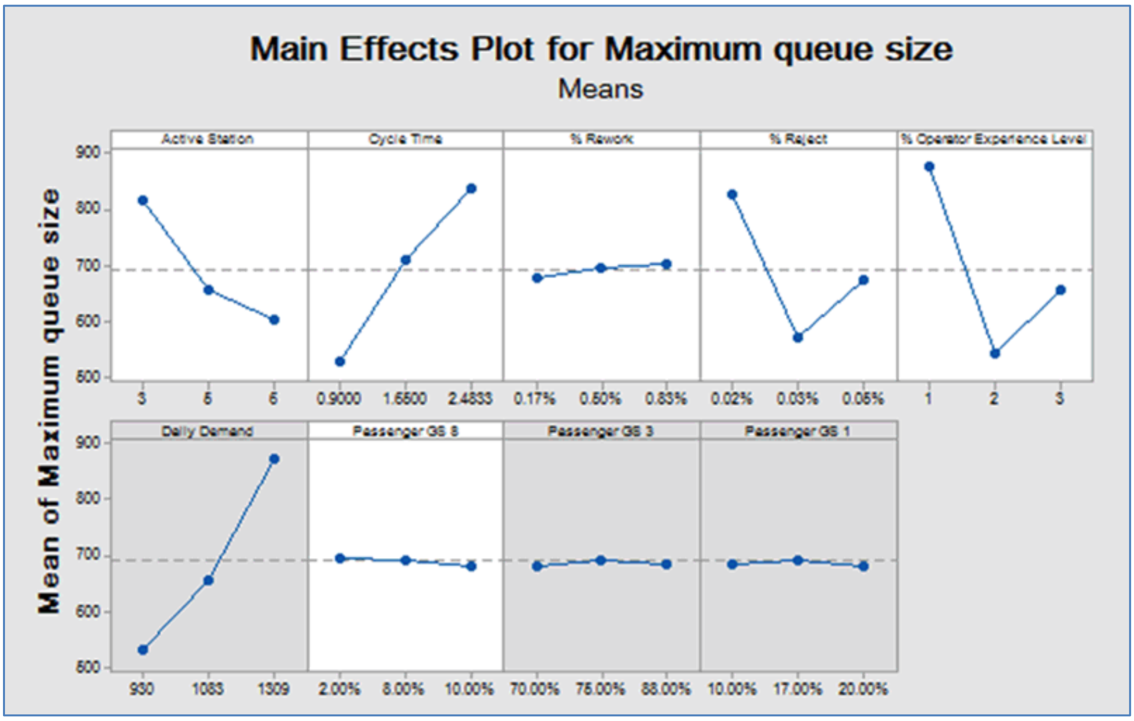

Figure 6-13 Main Effects Plot: MQS - Economy-Class Bag Drop

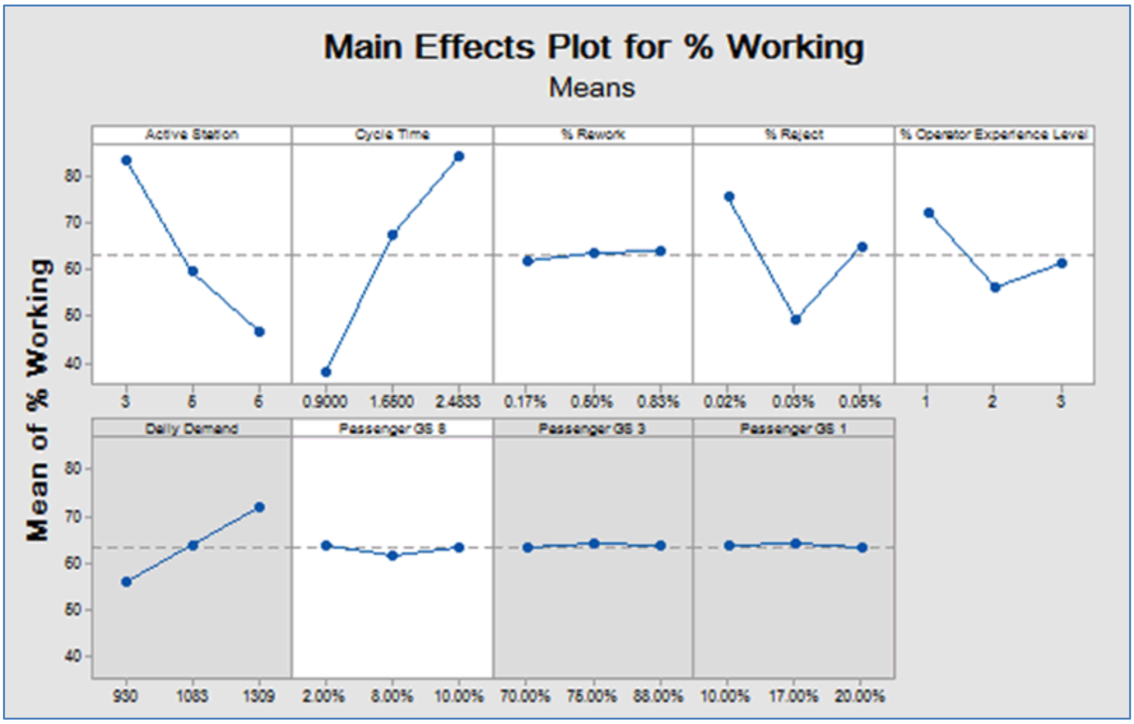

Figure 6-14 Main Effects Plot: Percentage Working Time - Economy-Class Bag Drop

For **%Working** (%Wo) (Figure 6-14) and **%Waiting** (%Wa) (Figure 6-15), additional interactions with 'Operator Experience' in processing stations, $F(2,26) = 3.369$, $p = 0$, and between **%Wo** and '% Reject', $F(2,26) = 3.369$, $p = 0.0021$ are both *highly* statistically significant. Interactions between **%Wo** & **%Wa** and ‘Daily Demand’, F(2,26) = 3.369, p = 0.0754 are both statistically significant.

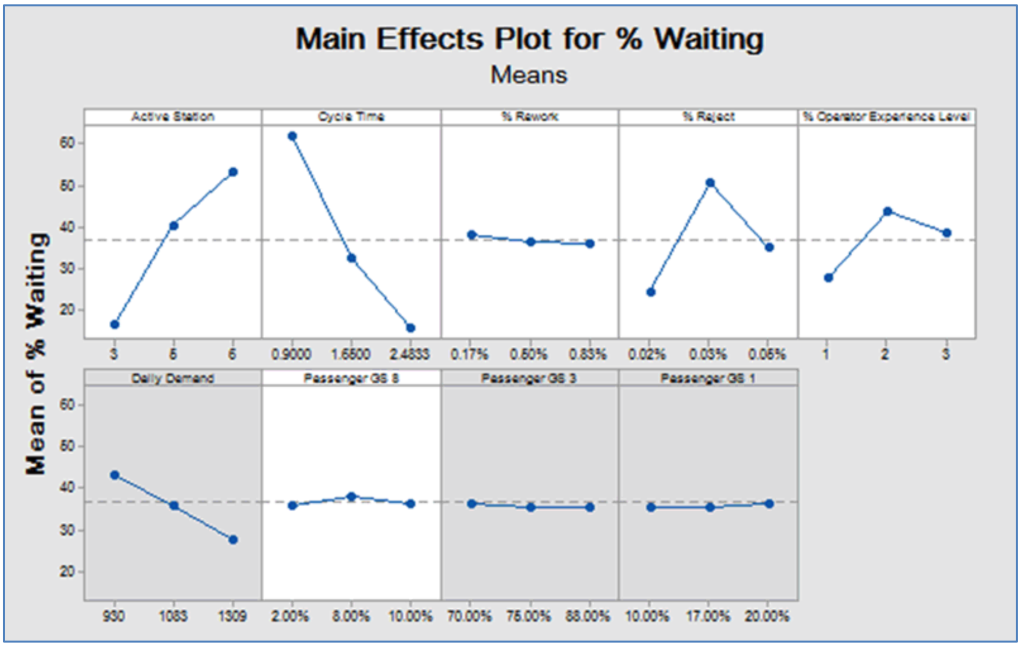

Figure 6-15 Main Effects Plot: Percentage Waiting Time - Economy-Class Bag Drop

Finally, for **WIP**(Figure 6-16), additional interactions with ‘% Working’, F(2,26) = 3.369, p = 0.0163; and ‘% Rejects’ are *very* statistically significant.

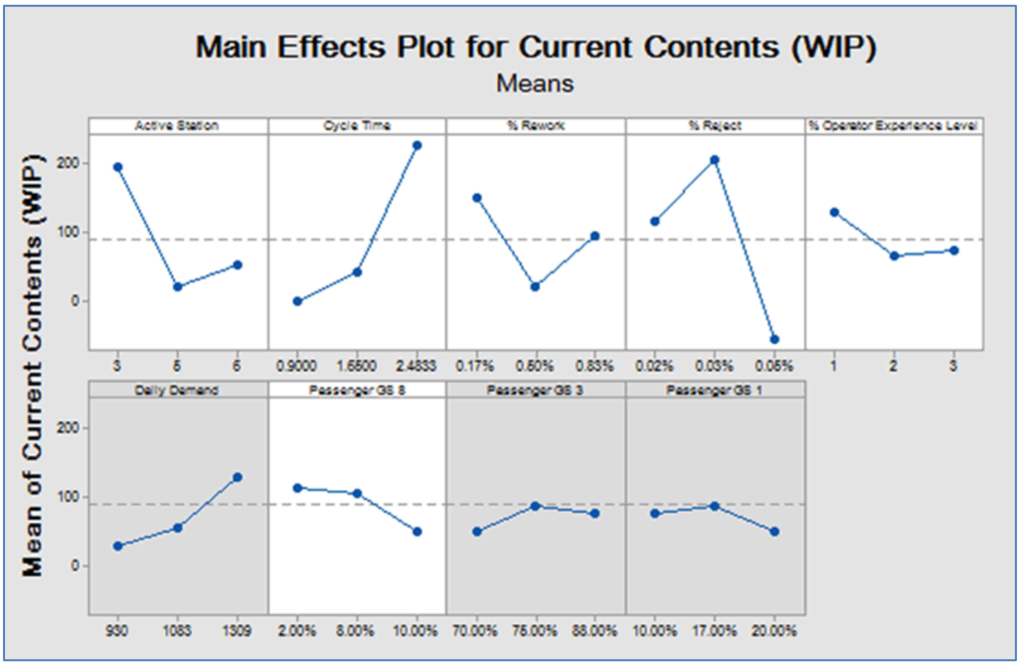

Figure 6-16 Main Effects Plot: WIP - Economy-Class Bag Drop

6.3.1.4Business-Class Standard Check-in

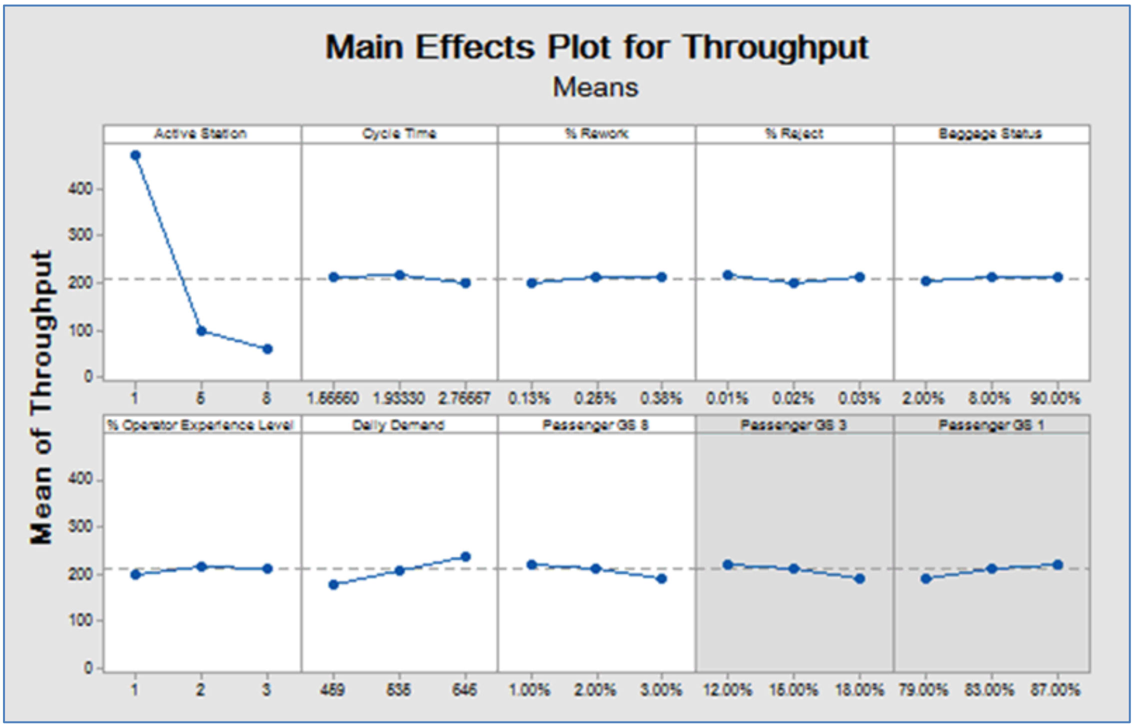

Figure 6-17 Main Effects Plot: Throughput - Business-Class Standard Check-in

A 10-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-17 to 6-22. Dependent variables were ‘throughput’, ‘AQT’, ‘MQS’, ‘Percentage of Working’, ‘Percentage of Waiting’, and ‘WIP’.

ANOVA results demonstrate the model themselves are *highly* or *very* statistically significant, $F(16,26)=2.0715$, $p \approx 0.000$ as it was in 5 of 6 cases tested where p varied between 0.0000 – 0.0111. In every case except ‘WIP’ interactions between the dependent variable and ‘Active Stations’, $F(2,26) = 3.369$, $p \approx 0$ are *highly* statistically significant with p varying between 0.0000 - 0.0004.

For **throughput** (TP) (Figure 6-17), the additional interaction between **TP** and Daily Demand, $F(2,26) = 3.369$, $p = 0.0360$ is statistically significant.

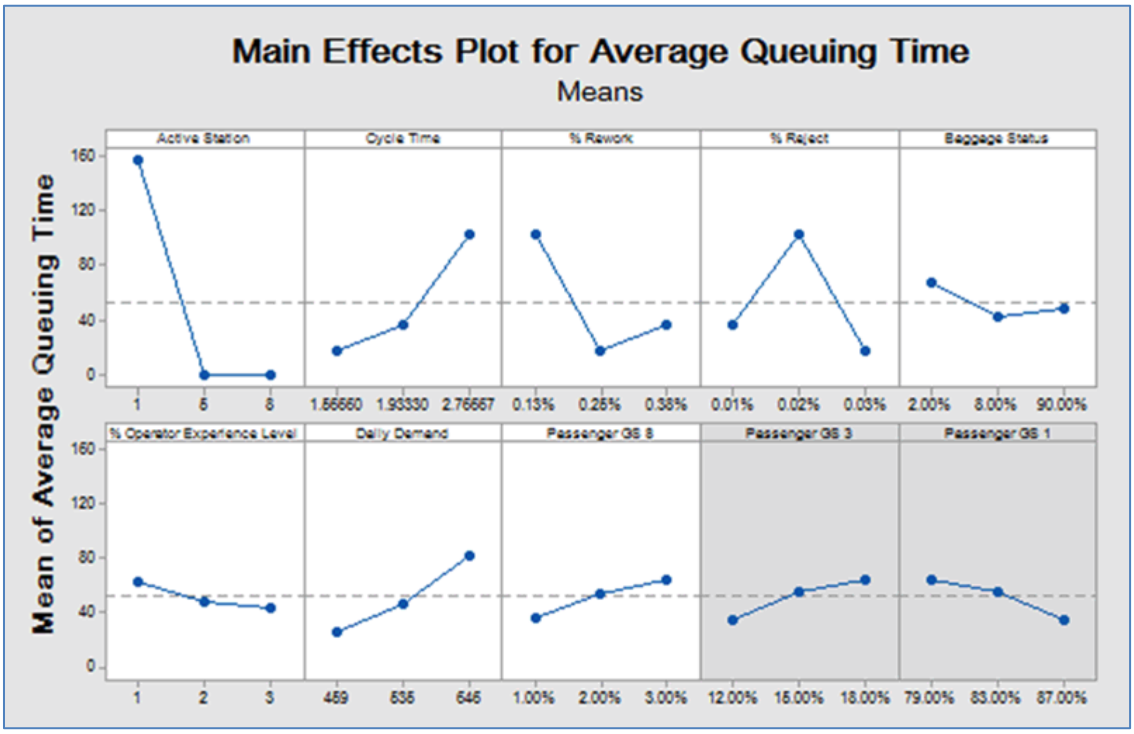

Figure 6-18 Main Effects Plot: AQT - Business-Class Standard Check-in

For **AQT** (Figure 6-18), the additional interactions with ‘cycle time’, $F(2,26) = 3.369$, $p = 0.0402$, ‘% Rework’ ,$F(2,26) = 3.369$, $p = 0.0404$ and ‘% Reject’ are all statistically significant.

Except for the interaction with ‘Active Stations’ previously reported, there are *no* statistically significant interactions between **MQS**(Figure 6-19) and any other factor variables.

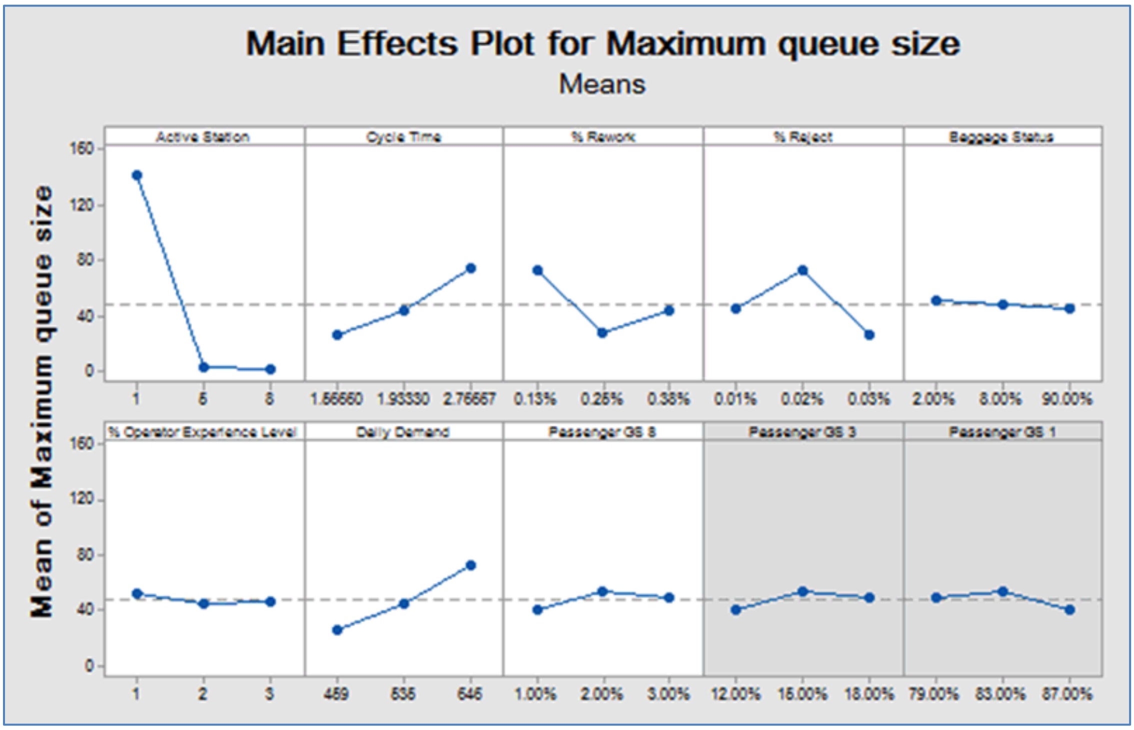

Figure 6-19 Main Effects Plot: MQS - Business-Class Standard Check-in

For the **%Working** (%Wo) (Figure 6-20) and **%Waiting** (%Wa) (Figure 6-21), additional interaction with 'cycle time', $F(2,26) = 3.369$, $p = 0.0001$ is *highly* statistically significant. Interactions between **%Wo** &**% Wa** and '% Rework', $F(2,26) = 3.369$, $p = 0.007$; '% Reject', $F(2,26) = 3.369$, $p = 0.0056$ and 'Daily Demand', $F(2,26) = 3.369$, $p = 0.0128$ are all *very* statistically significant.

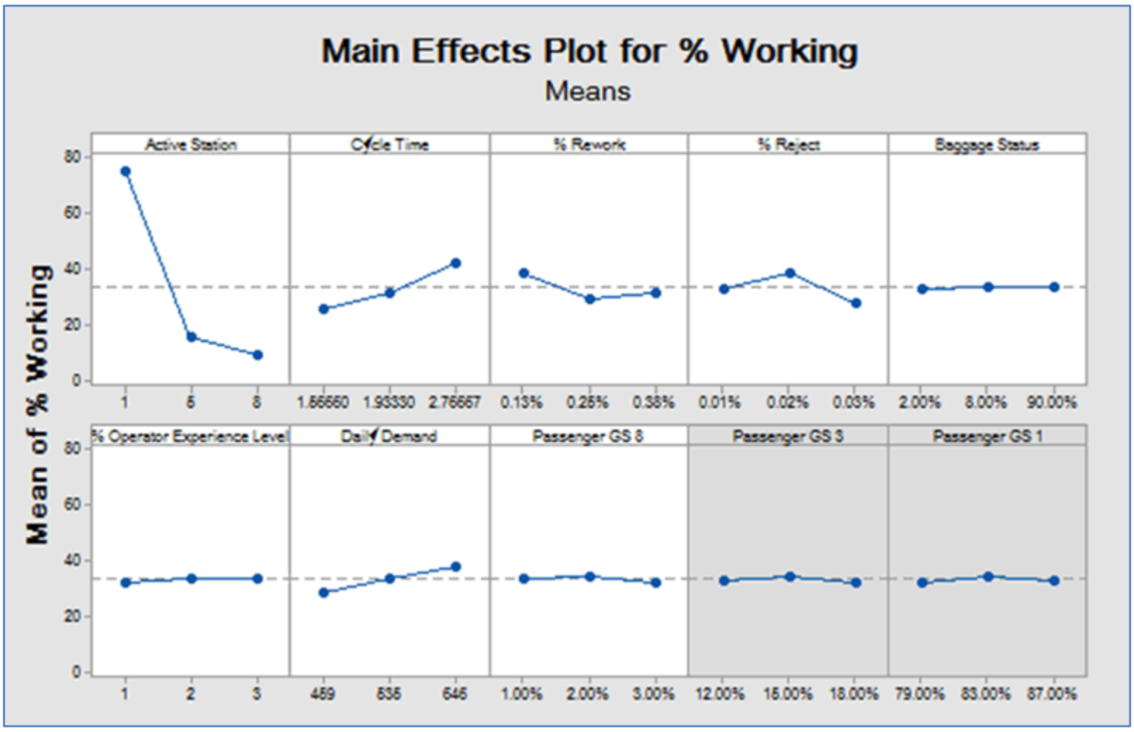

Figure 6-20 Main Effects Plot: Percentage Working Time - Business-Class Standard Check-in

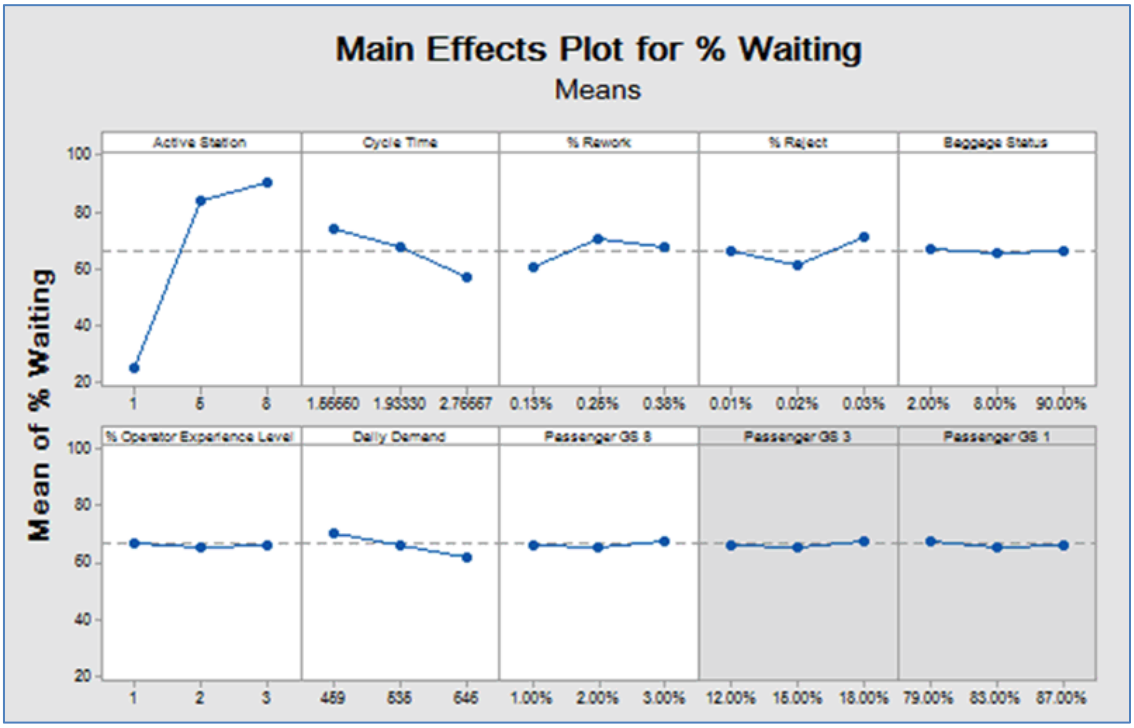

Figure 6-21 Main Effects Plot: Percentage Waiting Time - Business-Class Standard Check-in

When the model using **WIP** as the dependent variable (Figure 6-22) was tested there were no instances of interactions with any factor variables.

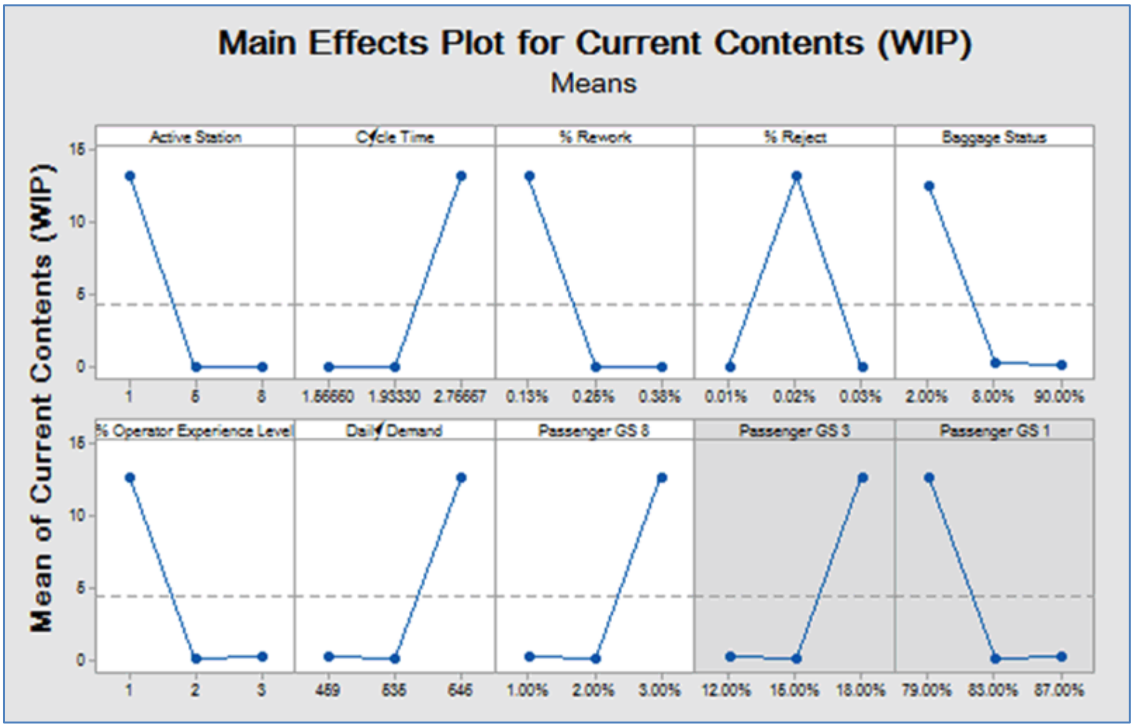

Figure 6-22 Main Effects Plot: WIP - Business-Class Standard Check-in

6.3.1.5 First-Class Standard Check-in

A 10-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-23 to 6-27. Dependent variables were 'Throughput', 'AQT', 'MQS', 'Percentage of Working', and 'Percentage of Waiting'.

The model of First-Class Standard Check-in is the most variable among those tested, though this is hardly surprising given the over-provision of active check-out counters.

With **throughput** (TP) (Figure 6-23) as the dependent variable, the model itself, F(14,26) = 2.1479, p = 0 is *highly* statistically significant. Interactions between **TP** and 'Active Stations', F(2,26) = 3.369, p = 0 and 'Daily Demand', F(2,26) = 3.369, p = 0.0026 are also *highly* statistically significant.

When **AQT**(Figure 6-24) is the dependent variable, the model itself, F (14,26) = 2.147, p= 0.1208 is *not* statistically significant. The interaction between **AQT** and 'Active Stations', F(2,26) = 3.369, p = 0.0244 is statistically significant.

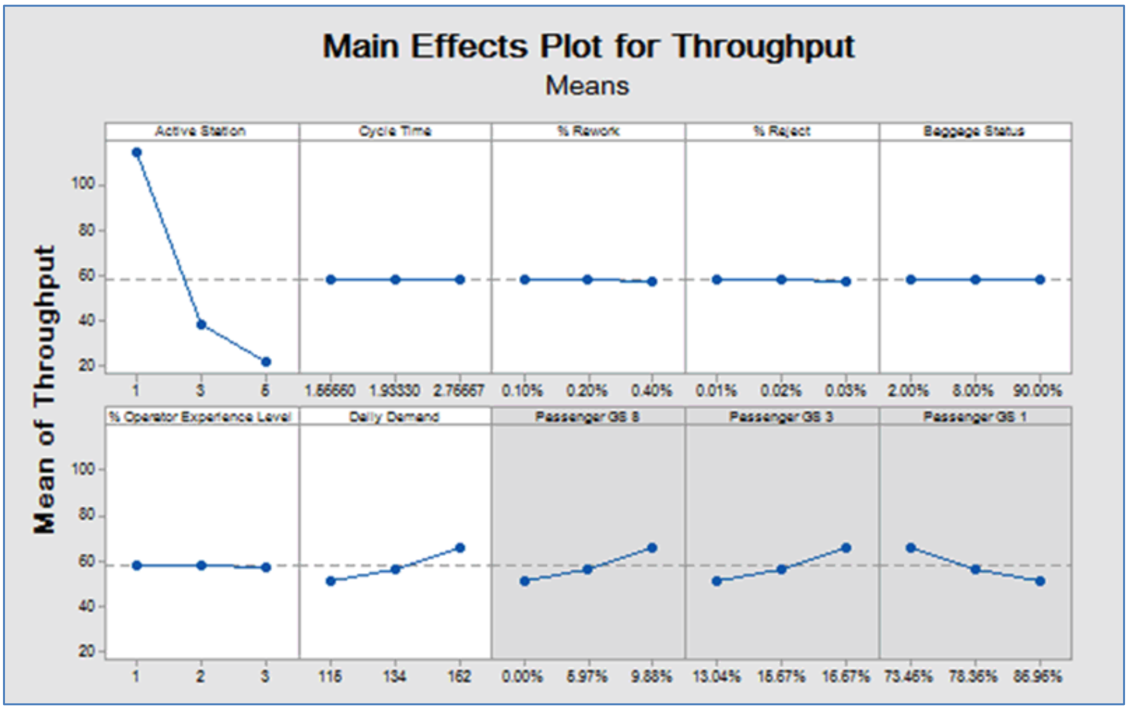

Figure 6-23 Main Effects Plot: Throughput - First-Class Standard Check-in

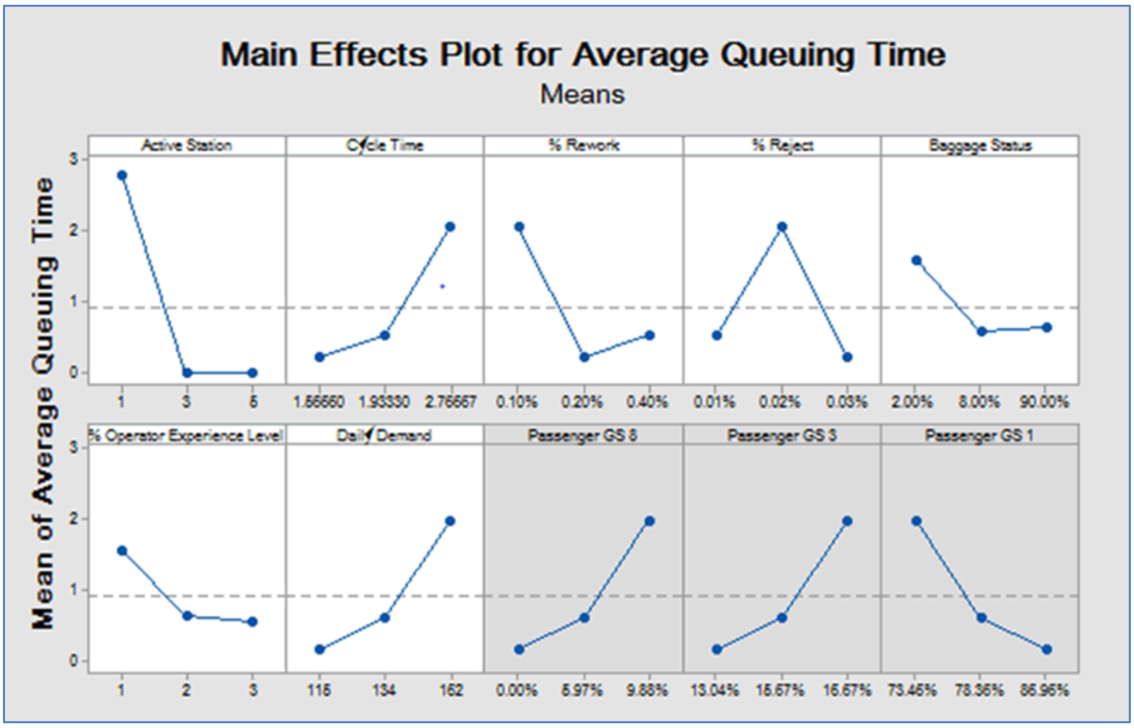

Figure 6-24 Main Effects Plot: AQT - First-Class Standard Check-in

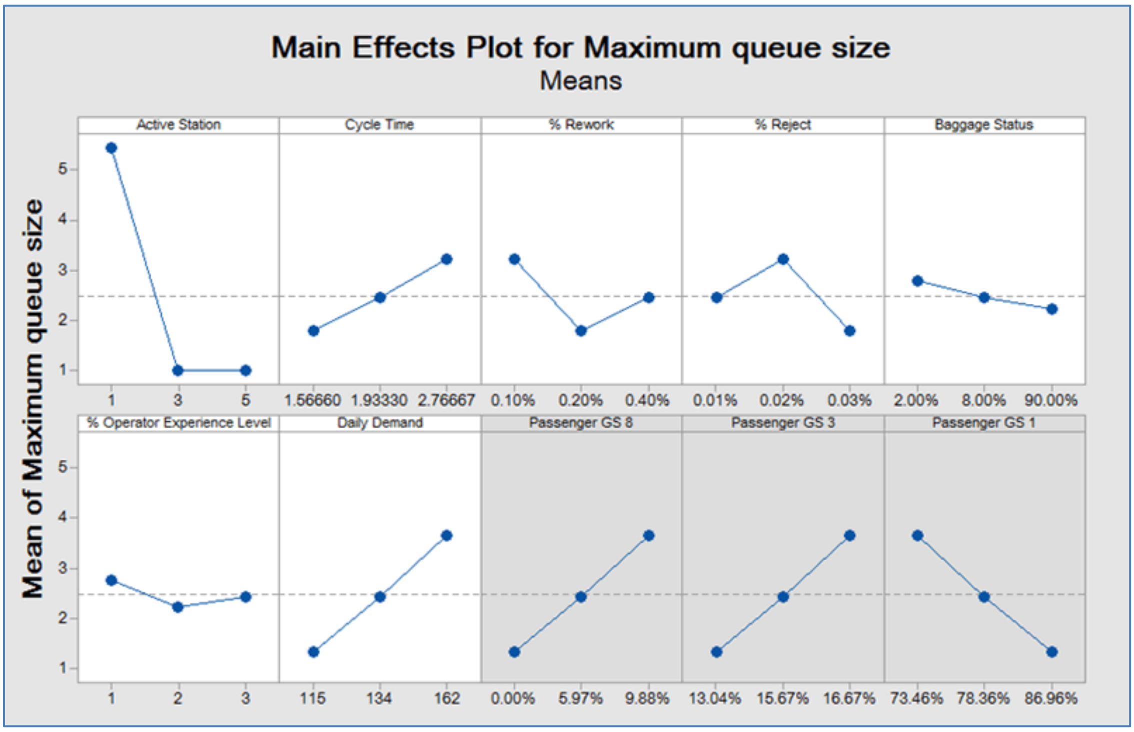

Figure 6-25 Main Effects Plot: MQS - First-Class Standard Check-in

With **MQS**(Figure 6-25) as the dependent variable, the model itself, F(14,26) = 2.1479, p = 0.0503 is statistically significant. Interactions between **TP** and 'Active Stations', F(2,26) = 3.369, p = 0.0011 is *highly* statistically significant.

For both **% Working** (%Wo) (Figure 6-26) and **% Waiting** (%Wa) (Figure 6-27) both models, F(14,26) = 2.1479, p = 0, are *highly* statistically significant. Interactions between **%Wo &% Wa**, 'Active Stations', F(2,26) = 3.369, p = 0 and 'cycle time', F(2,26) = 3.369, p = 0 of processing stations are both *highly* statistically significant. Interactions between **%Wo &% Wa**, '% Rework', F(2,26) = 3.369, p = 0.0097, '% Rejects', F(2,26) = 3.369, p = 0.0103 and 'Daily Demand', F(2,26) = 3.369, p = 0.0048 are each *very* statistically significant.

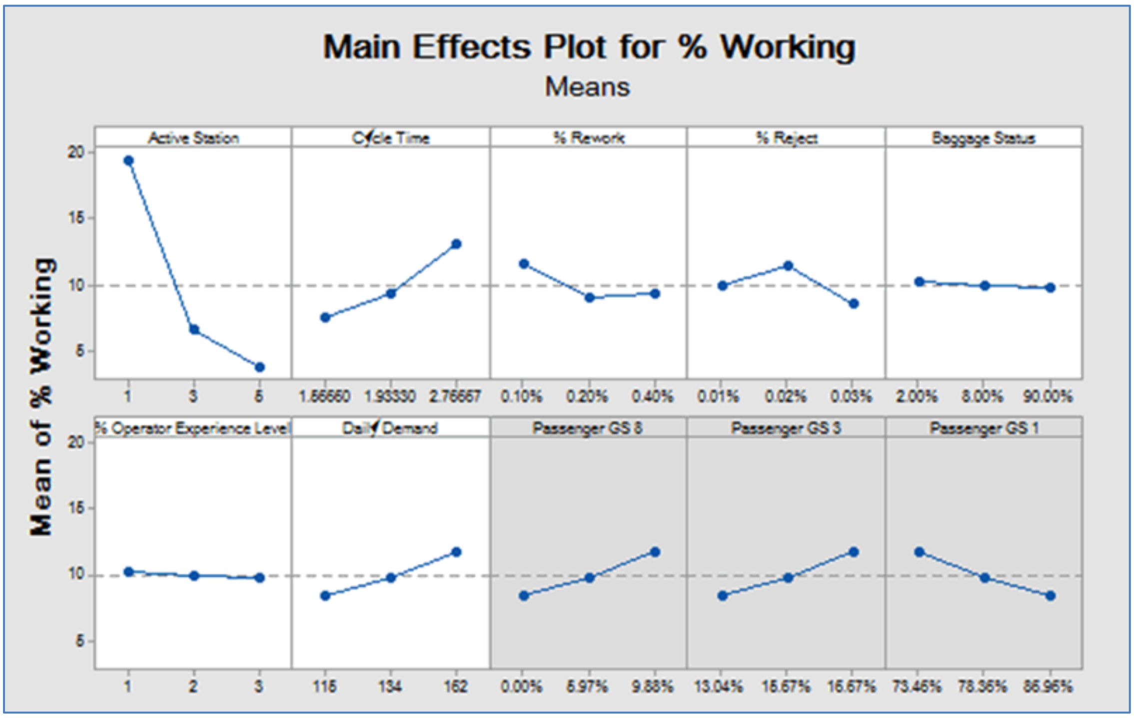

Figure 6-26 Main Effects Plot: Percentage Working Time - First-Class Standard Check-in

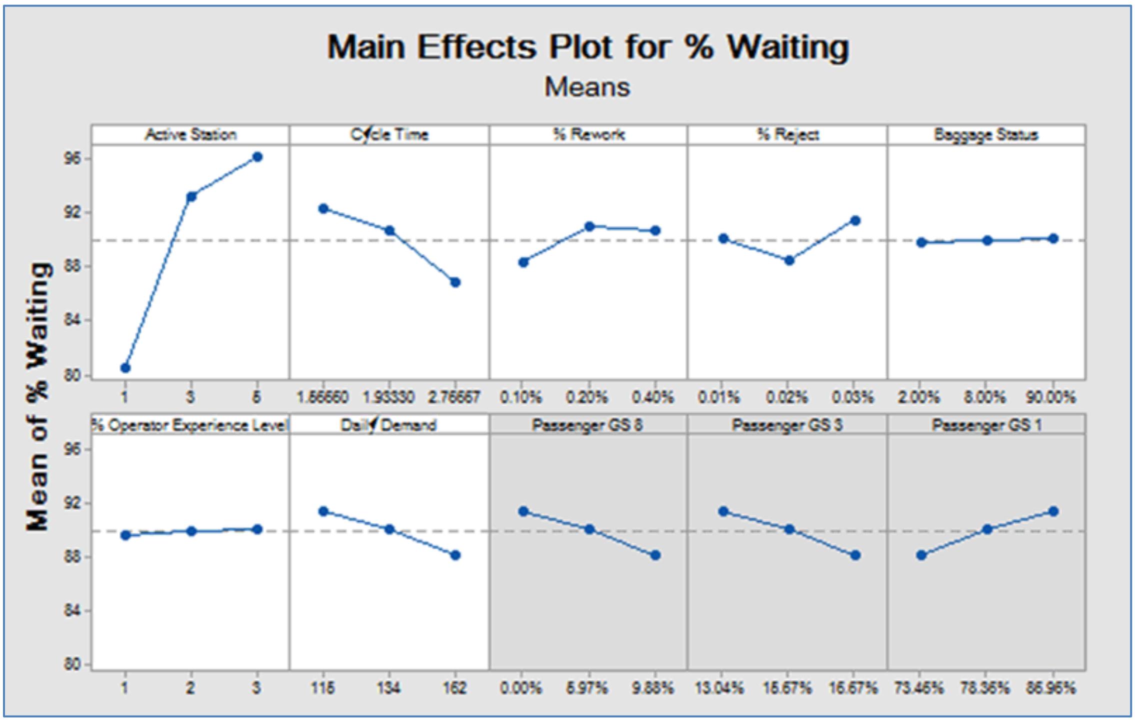

Figure 6-27 Main Effects Plot: Percentage Waiting Time - First-Class Standard Check-in

6.3.2 Emigration

6.3.2.1Emigration Economy-Class

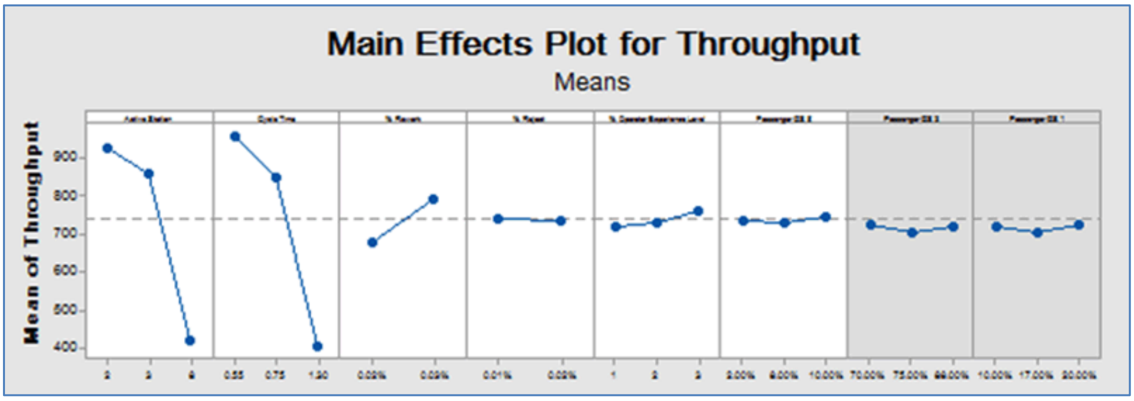

Figure 6-28 Main Effects Plot: Throughput - Economy-Class Border Control

An 8-way factorial ANOVA was performed to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-28 to 6-33. Dependent variables were ‘throughput’, ‘AQT’, ‘MQS’, ‘Percentage of Working’, ‘Percentage of Waiting’, and ‘WIP’.

ANOVA showed that **throughput**, **AQT**, **MQS**, **Percentage of Working** and **Percentage of Waiting**(Figures 6-28 to 6-33) all demonstrated that the model itself $F(10,26) = 2.2197$, $p \approx 0$ is *highly* statistically significant with p varying between 0.0000 to 0.0005. Interactions between each of these five dependent variables, ‘Active Stations’, $F(2,26) = 3.369$, $p \approx 0$ (p-value range 0.0000 - 0.0003), and ‘cycle time’, $F(2,26) = 3.369$, $p \approx 0$ (p-value range 0.0000 - 0.0012) are all *highly* statistically significant.

The additional interaction between the dependent variable **throughput** and ‘% Rework’, $F(1,26) = 4.2252$, $p = 0.0301$ (Figure 6-28) is *very* statistically significant.

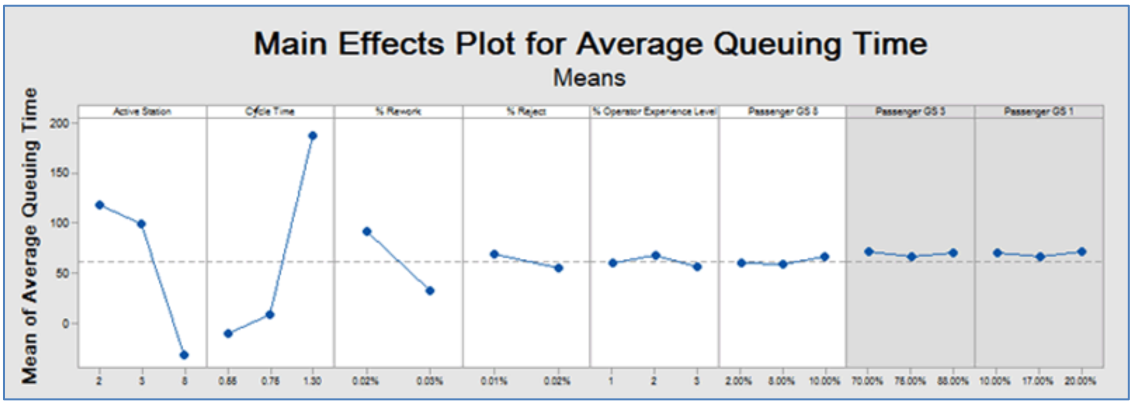

Figure 6-29 Main Effects Plot: AQT - Economy-Class Border Control

A further interaction between **AQT** and '% Rework', $F(1,26) = 4.2252$, $p = 0.0017$ (Figure 6-29) is *very* statistically significant, together with the interaction between **MQS** and '% Rework', $F(1,26) = 4.2252$, $p = 0.003$ (Figure 6-30) is also *very* statistically significant.

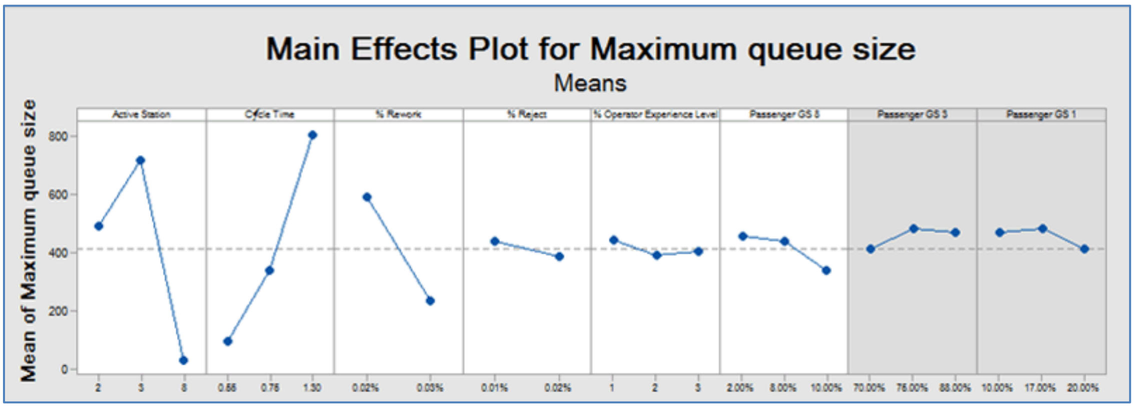

Figure 6-30 Main Effects Plot: MQS - Economy-Class Border Control

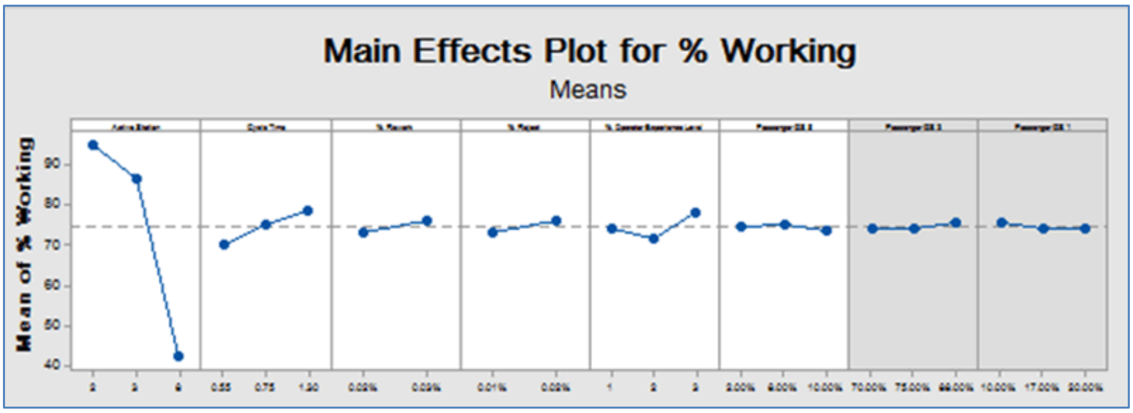

Figure 6-31 Main Effects Plot: Percentage Working Time - Economy-Class Border Control

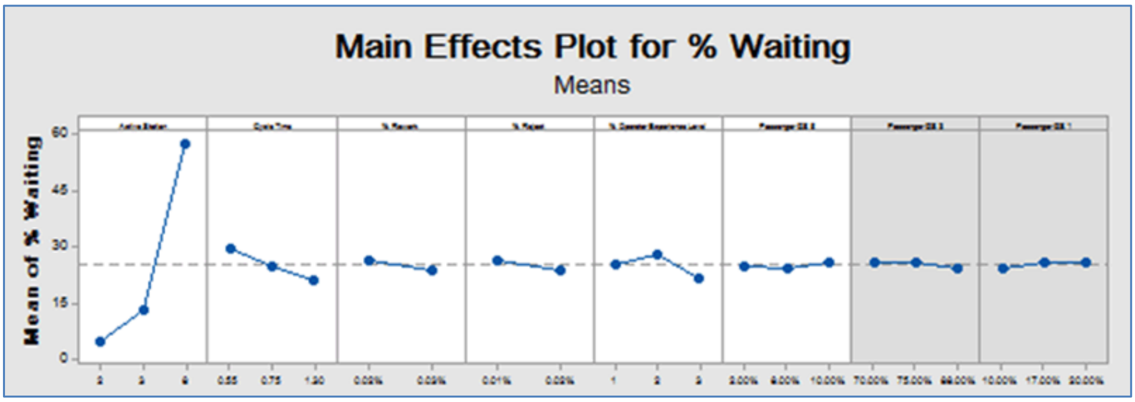

Figure 6-32 Main Effects Plot: Percentage Waiting Time - Economy-Class Border Control

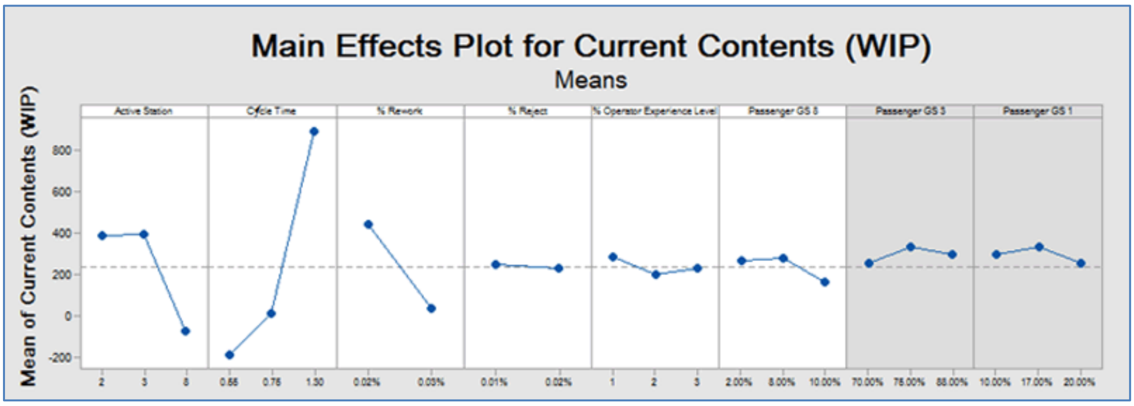

Figure 6-33 Main Effects Plot: WIP - Economy-Class Border Control

The model for **WIP** (Figure 6-33) is *very* statistically significant at F(10,26) = 2.2197, p = 0.0182. In a further departure from other models in the Economy Emigration group, the interaction between **WIP** and ‘Active Stations’, F(2,26) = 3.369, p = 0.2558 is *not* statistically significant though the interaction between **WIP** and ‘cycle time, F(2,26) = 3.369, p = 0.0012 is, like other models in this group, *highly* statistically significant. The interaction between **WIP** and ‘% Rework’, F(1,26) = 4.2252, p = 0.0165 is statistically significant.

6.3.2.2 Emigration First and Business-Class

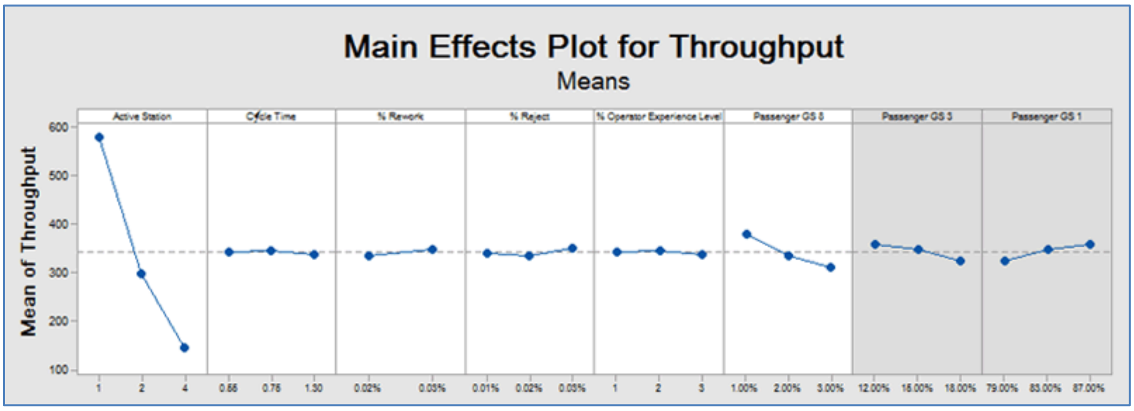

Figure 6-34 Main Effects Plot: Throughput – First & Business-Class Border Control

An 8-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-34 to 6-38. Dependent variables were 'throughput', 'AQT', 'MQS', 'Percentage of Working', and 'Percentage of Waiting'.

Using factorial ANOVA to test **throughput** (TP) (Figure 6-34) indicated the model itself, $F(11,26) = 2.2197$, $p = 0$ is *highly* statistically significant together with the interaction between **TP** and 'Active Stations', $F(2,26) = 3.369$, $p = 0$.

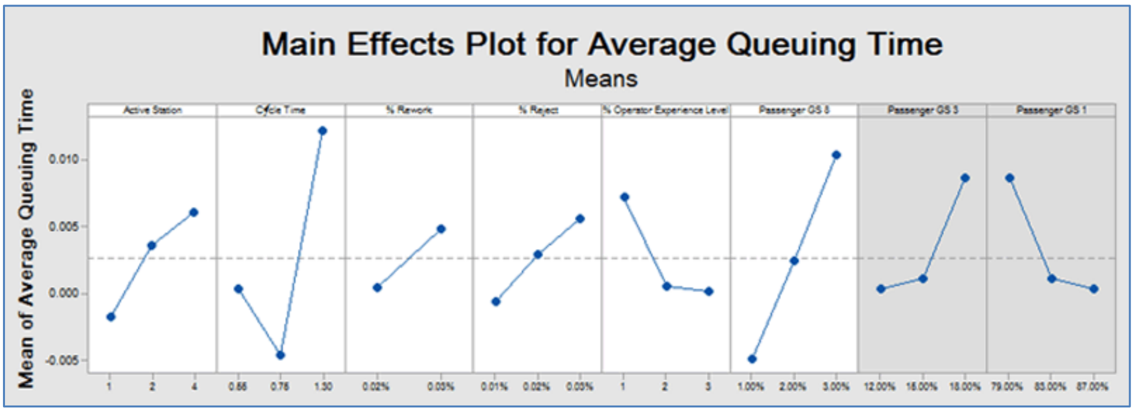

Figure 6-35 Main Effects Plot: AQT – First & Business-Class Border Control

In this group ANOVA tests performed on **AQT** (Figure 6-35) and **MQS** (Figure 6-36) showed there were *no* statistically significant interactions, *nor* were either of the models statistically significant meaning the null hypothesis is rejected and that results of signal-to-noise ratios shown in Figures 6-35 & 6-36 are ignored.

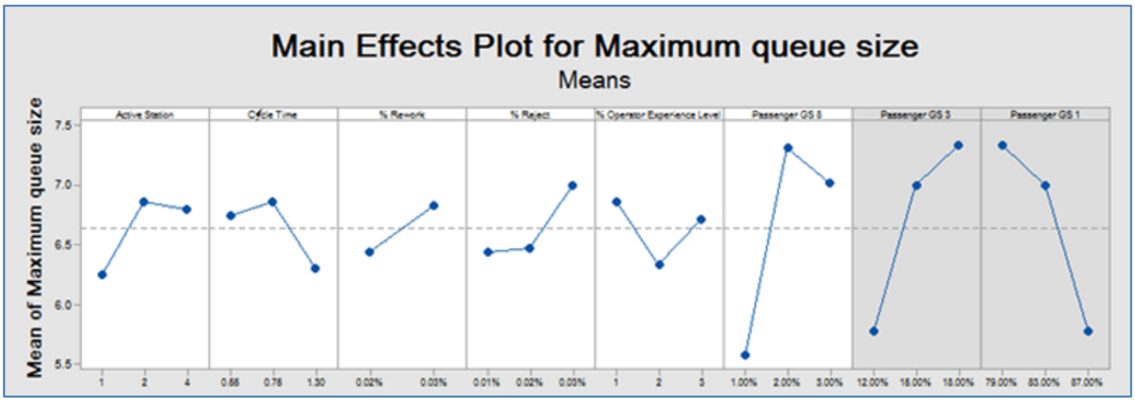

Figure 6-36 Main Effects Plot: MQS – First & Business-Class Border Control

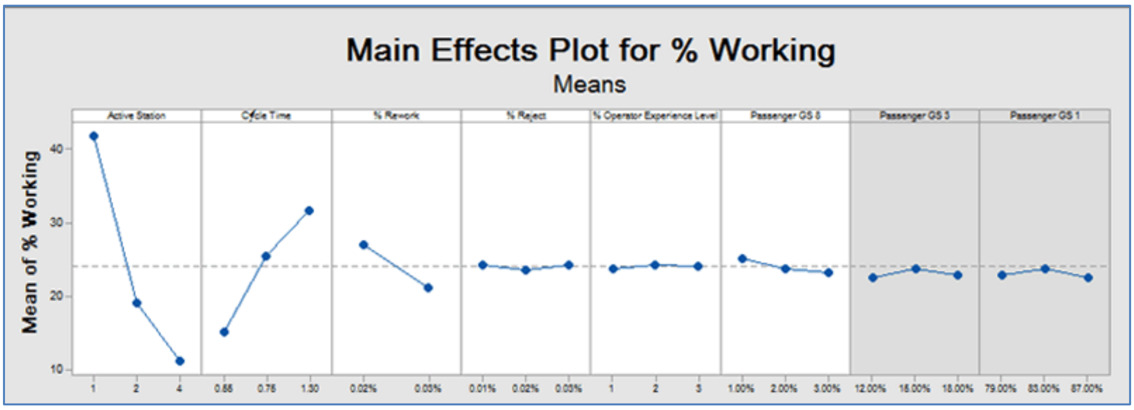

Figure 6-37 Main Effects Plot: Percentage Working Time – First & Business-Class Border Control

ANOVA tests on **% Working** (%Wo) (Figure 6-37) and **% Waiting** (%Wa) (Figure 6-38) both gave similar results with both models, $F(11,26) = 2.2197$, $p = 0$ being *highly* statistically significant. Interactions between **%Wo** & **%Wa**, ‘Active Stations’, $F(2,26) = 3.369$, $p = 0$ and ‘cycle time’, $F(2,26) = 3.369$, $p = 0$ were all *highly* statistically significant. Interactions between **%Wo** & **%Wa** and ‘% Rework’, $F(1,26) = 4.2252$, $p = 0.0238$ were both statistically significant.

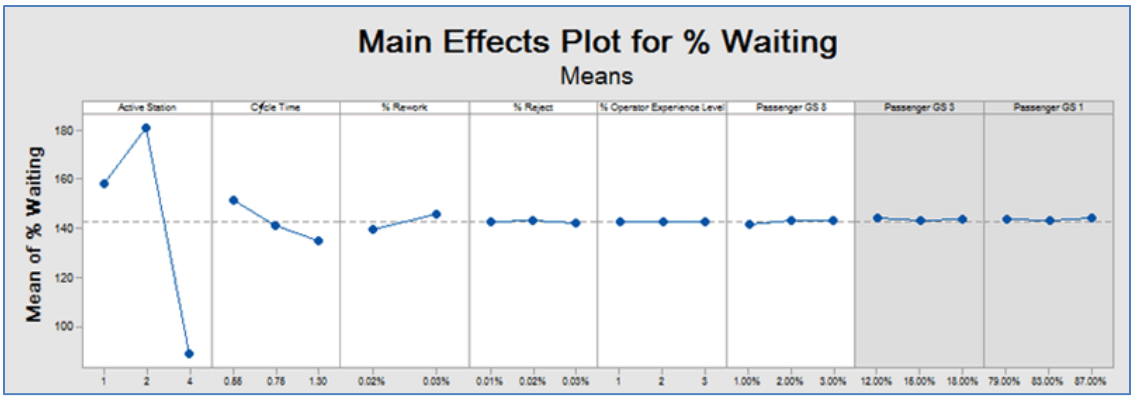

Figure 6-38 Main Effects Plot: Percentage Waiting Time – Emigration First & Business-Class

6.3.3 Security Screening

6.3.3.1 Economy-Class Security Screening

A 5-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-39 to 6-44. Dependent variables were 'throughput', 'AQT', 'MQS', 'Percentage of Working', 'Percentage of Waiting' and WIP. Results of interactions are mixed and reported for the model used for each dependent variable.

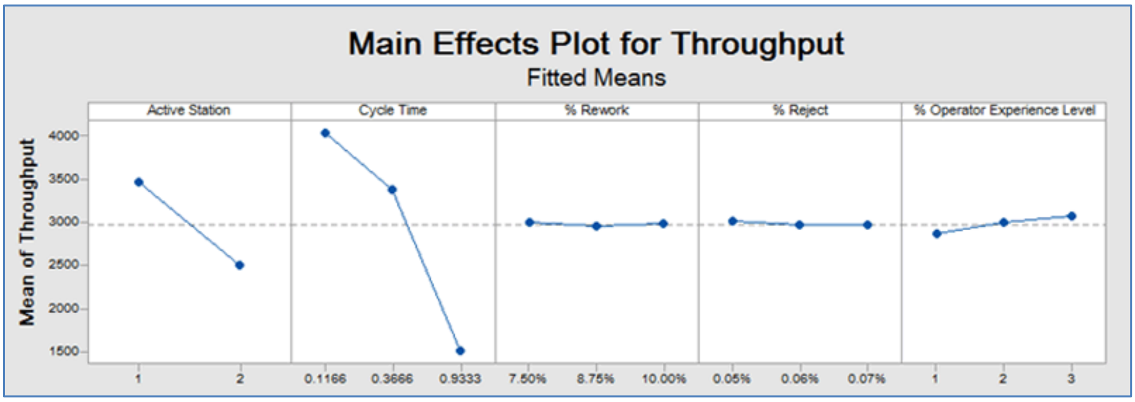

Figure 6-39 Main Effects Plot: Throughput – Economy-Class Security Screening

The model itself for **throughput** (TP) $F(9,26) = 2.2655$, $p = 0.0017$(Figure 6-39) and **AQT**$F(9,26) = 2.2655$, $p = 0.0017$(Figure 6-40) are both *highly* statistically significant. The interaction between **TP** and the number of Active Stations, $F(1,26) = 4.2252$, $p = 0$ is also *highly* statistically significant while the interaction between **AQT**, and 'Active Stations' indicates *no* statistical significance. In the cases of both **TP** and **AQT**, the interaction with 'cycle time', $F(2,26) = 3.369$, $p = 0$ is *highly* statistically significant.

The interaction between **TP** and the Percentage of Rework, $F(2,26) = 3.369$, $p = 0.0141$ is *very* statistically significant.

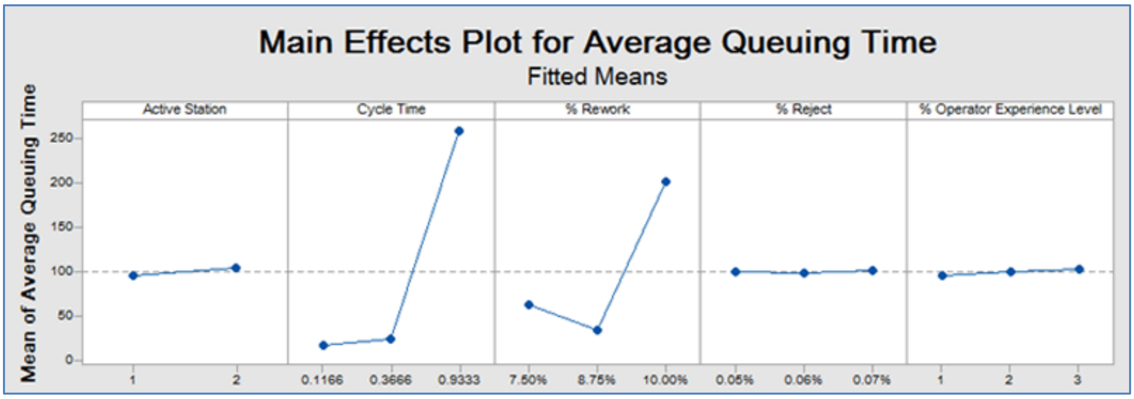

Figure 6-40 Main Effects Plot: AQT – Economy-Class Security Screening

The model for **MQS**(Figure 6-41) is itself statistically significant, $F(9,26) = 2.2655$, $p = 0.0284$ even though ANOVA indicates there is *no* statistical significance in the interaction between **MQS** and 'Active Stations'. However, the interaction between **MQS** and 'cycle time', $F(2,26) = 3.369$, $p = 0.0021$ is *very* statistically significant.

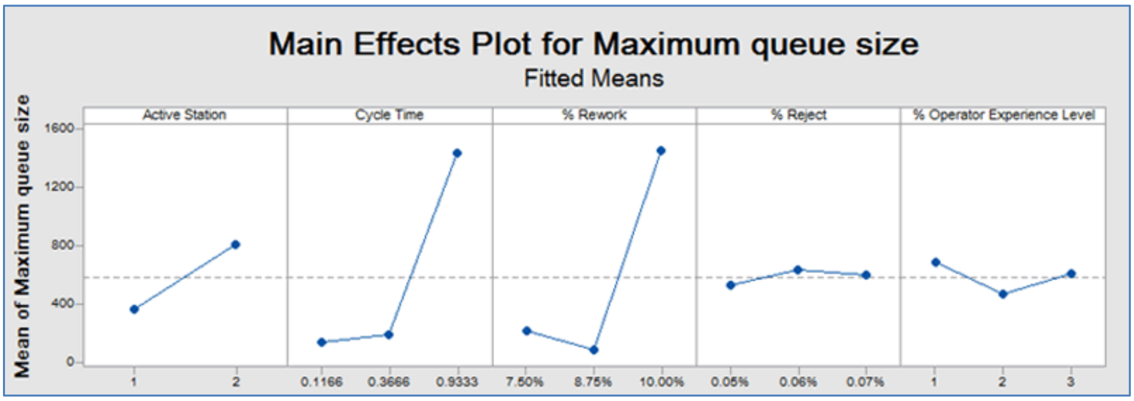

Figure 6-41 Main Effects Plot: MQS – Economy-Class Security Screening

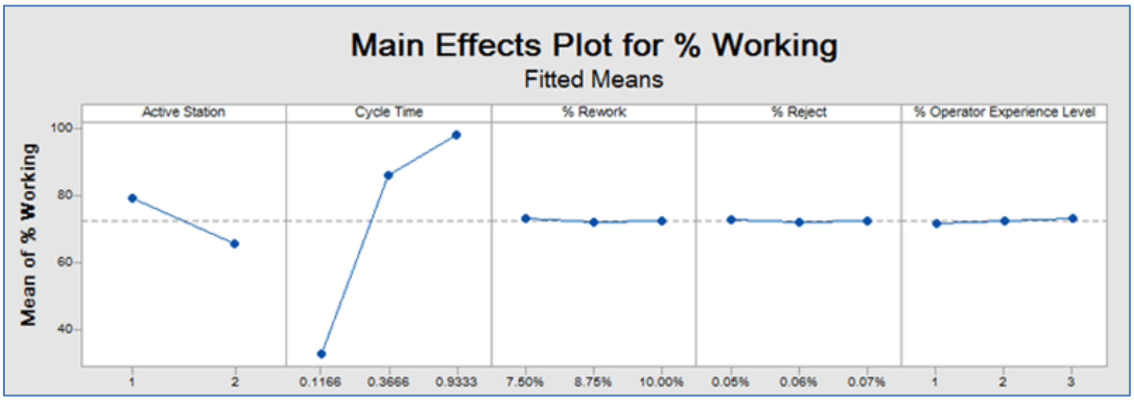

Figure 6-42 Main Effects Plot: Percentage Working Time – Economy-Class Security Screening

The ANOVA models for **% Working** (%Wo) (Figure 6-42) and **% Waiting** (%Wa) (Figure 6-43),F(8,26) = 2.2655, p = 0 indicate both models are *highly* statistically significant. Interactions between both dependent variables **%Wo** and **%Wa**, 'Active Stations', F(1,26) = 4.2252, p = 0 and 'cycle time', F(2,26) = 3.369, p = 0 are all *highly* statistically significant. Interactions between **%Wo** and **%Wa** and '% Rework', F(2,26) = 3.369, p = 0.0143 are both statistically significant.

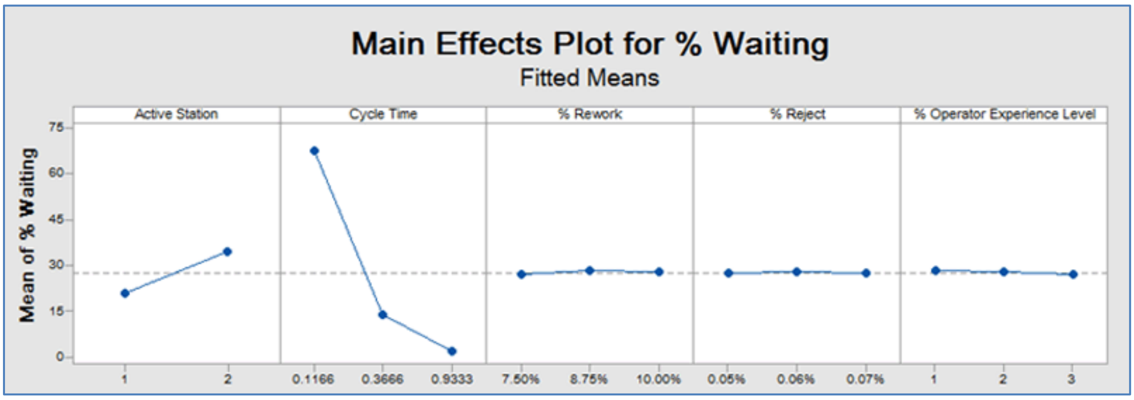

Figure 6-43 Main Effects Plot: Percentage Waiting Time – Economy-Class Security Screening

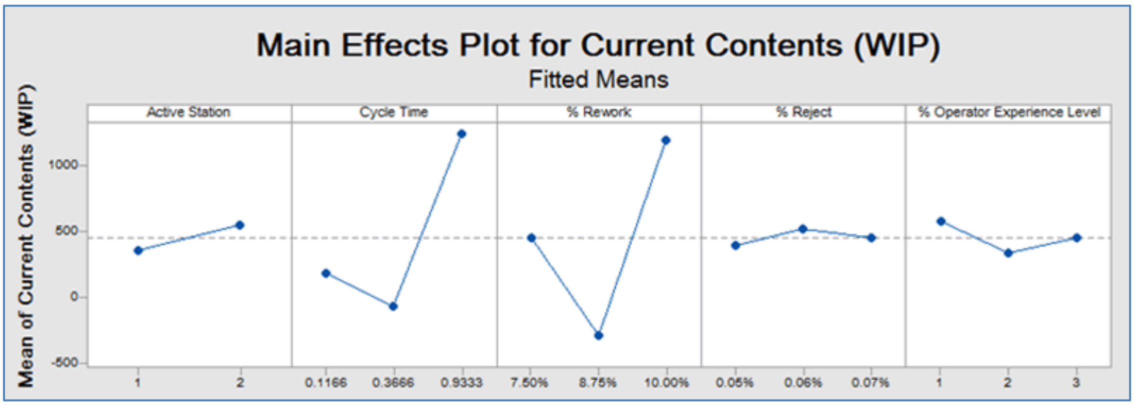

Figure 6-44 Main Effects Plot: WIP – Economy-Class Security Screening

The ANOVA test indicated the model for **WIP** F(8,26) = 2.2655, p = 0.0019 (Figure 6-44) is itself statistically significant. While interactions between the dependent variable **WIP** and 'Active Stations' indicates *no* statistical significance, that between **WIP** and 'cycle time', F(2,26) = 3.369, p = 0.0001 is *highly* statistically significant and between **WIP** and the '% Rework', F(2,26) = 3.369, p = 0.0134 is *very* statistically significant.

6.3.3.2 First and Business-Class Security Screening

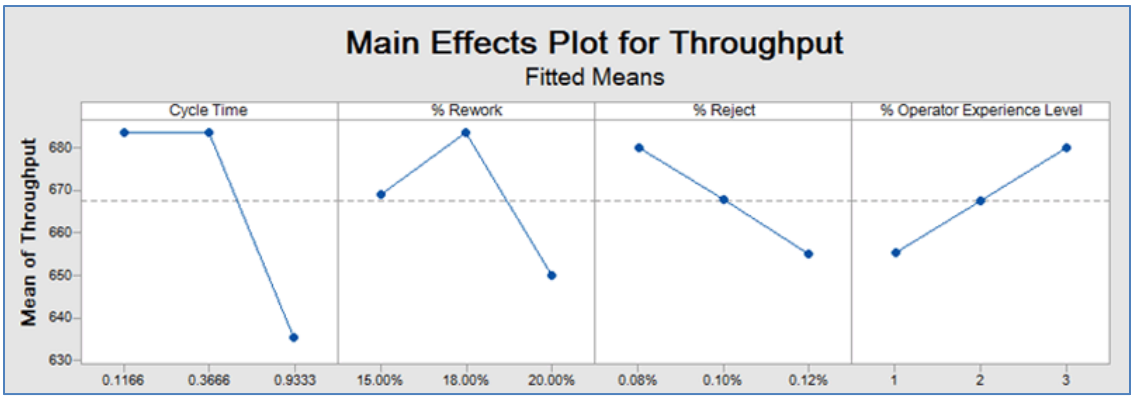

Figure 6-45 Main Effects Plot: Throughput – First & Business-Class Security Screening

A 4-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-45 to 6-49. Dependent variables were 'throughput', 'AQT', 'MQS', 'Percentage of Working' and 'Percentage of Waiting'. Results of interactions are mixed and reported for the model used for each dependent variable.

ANOVA results indicate there are *no* statistically significant interactions between the dependent variable **throughput** (TP)and any factor variable and that the model itself is *not* statistically significant. The null hypothesis is therefore rejected and all signal-to-noise ratios for the **TP** model shown in Figure 6-45 are disregarded.

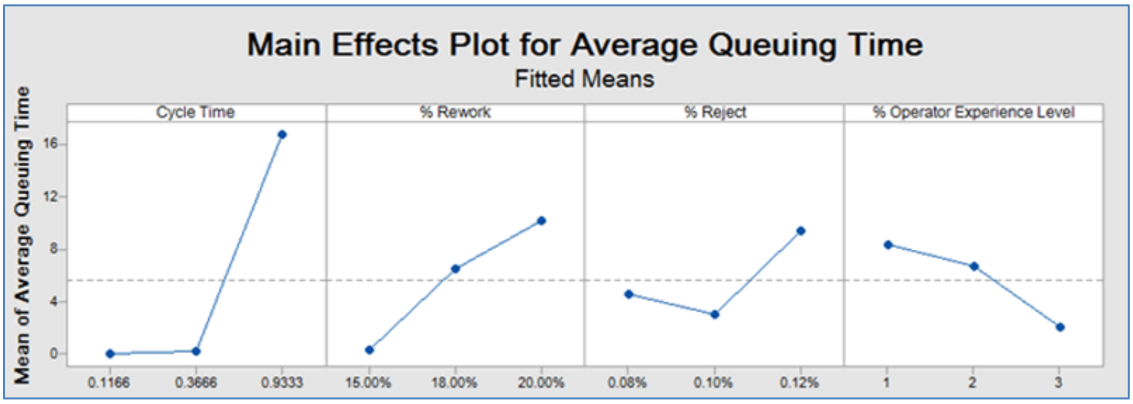

Figure 6-46 Main Effects Plot: AQT – First & Business-Class Security Screening

ANOVA results show that models for **AQT**, F(8,26) = 2.3205, p = 0.0374 (Figure 6-46) and **MQS**, F(8,26) = 2.3205, p = 0.0304(Figure 6-47) are statistically significant. Interactions between **AQT** and 'cycle time', F(2,26) = 3.369, p = 0.0073 and **MQS** and 'cycle time', F(2,26) = 3.369, p = 0.0052 are both *very* statistically significant.

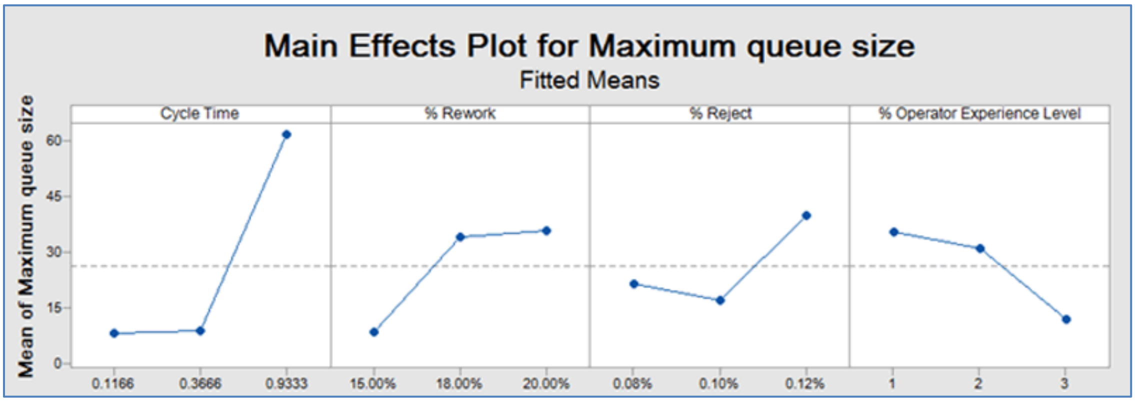

Figure 6-47 Main Effects Plot: MQS – First & Business-Class Security Screening

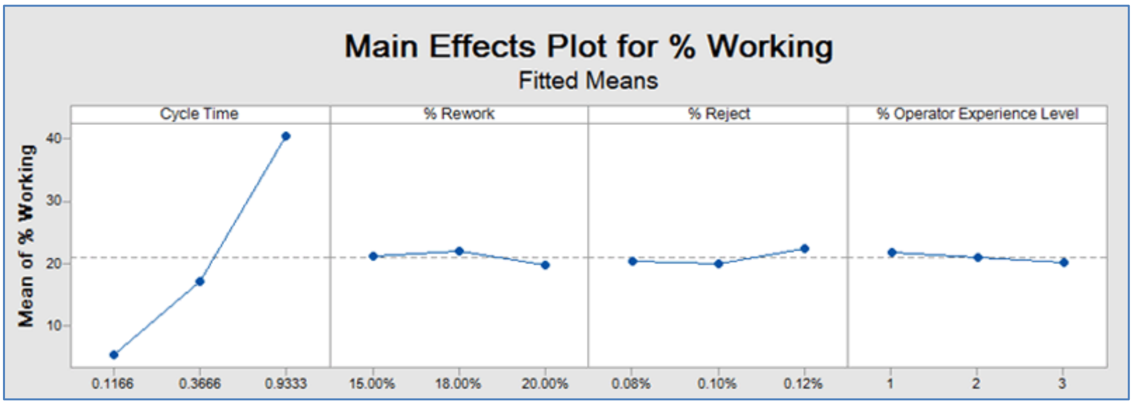

Figure 6-48 Main Effects Plot: Percentage Working Time – First & Business-Class Security Screening

ANOVA results demonstrate that for the both **% Working** time (%Wo), (Figure 6-48) and **% Waiting** time (%Wa), (Figure 6-49) results F(8,26) = 2.3205, p = 0 the models themselves are *highly* statistically significant. Interactions between **%Wo** & **%Wa** and 'cycle time', F(2,26) = 3.369, p = 0 are both *highly* statistically significant also.

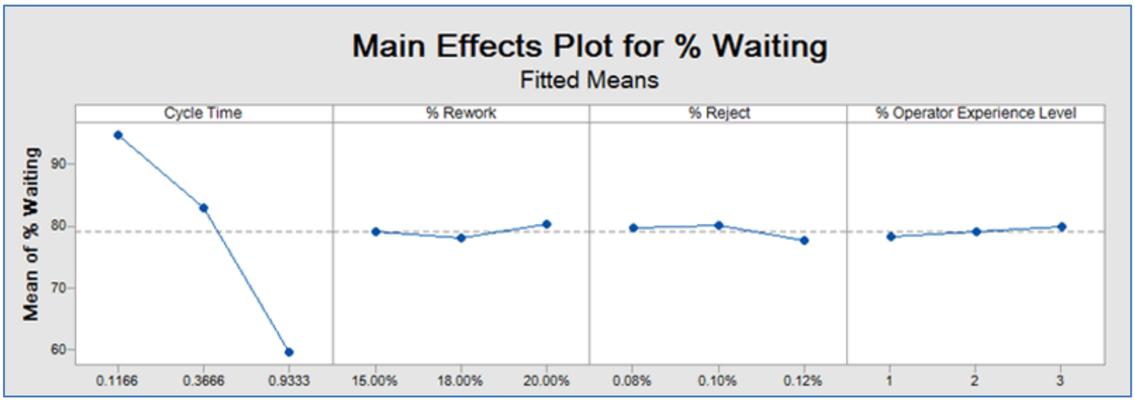

Figure 6-49 Main Effects Plot: Percentage Waiting Time – First & Business-Class Security Screening

6.3.3.3 Transfer Passengers Security Screening

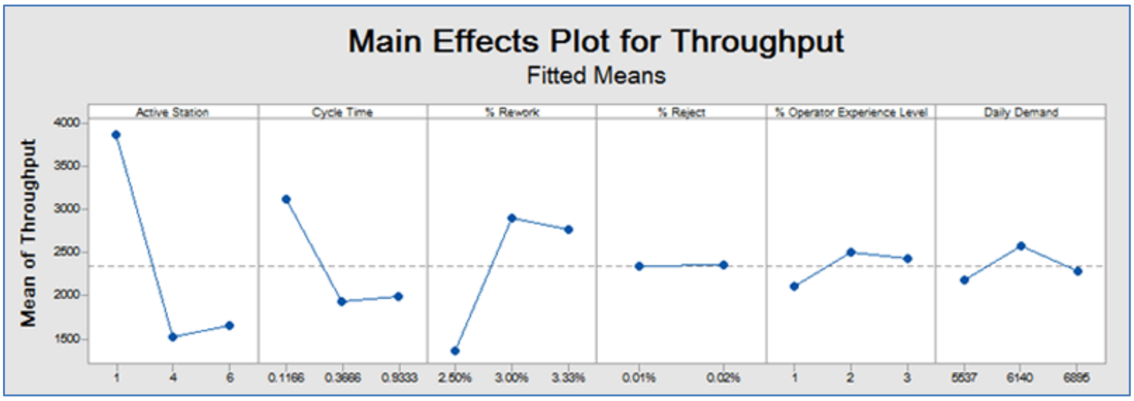

Figure 6-50 Main Effects Plot: Throughput – Transfer Passengers' Security Screening

A 6-way factorial ANOVA was run to test the main effects for various dependent variables using results from twenty-seven experiments to examine each of the factors shown in Figures 6-50 to 6-55. Dependent variables were 'throughput', 'AQT', 'MQS', 'Percentage of Working', 'Percentage of Waiting' and 'WIP'.

ANOVA results showed that for each of the six dependent variables listed above, the models itself, F(11,26) = 2.2197, p ≈ 0, are *highly* statistically significant with values for p-values varying between 0.0000 - 0.0009. Results for each of the six dependent variables and 'Active Stations', F(2,26) = 3.369, p ≈ 0 are each *highly* statistically significant with p-values varying between 0.0000 - 0.0001.

Interactions between dependent variables **AQT** (Figure 6-51), **MQS** (Figure 6-52), **Percentage of Working** (Figure 6-53), and **Percentage of Waiting** (Figure 6-54) and 'cycle time', F(2, 26) = 3.369, p=0 are all *highly* statistically significant.

In two models, **throughput** (Figure 6-50) and **WIP** (Figure 6-55) with interactions with 'cycle time', F(2,26) = 3.369, p = 0.0055& 0.0057 respectively and '% Rework', F(2,26) = 3.369, p = 0.0071/0.0121 respectively, interactions are each *very* statistically significant.

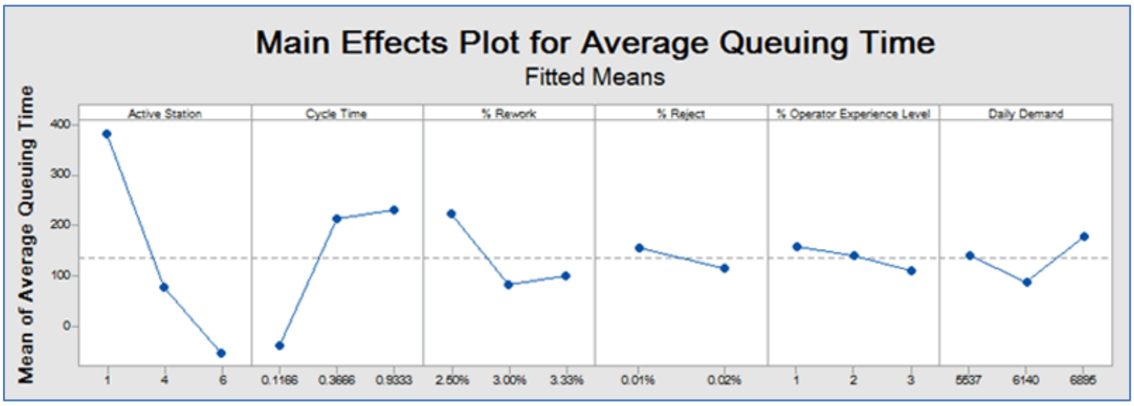

Figure 6-51 Main Effects Plot: AQT – Transfer Passengers' Security Screening

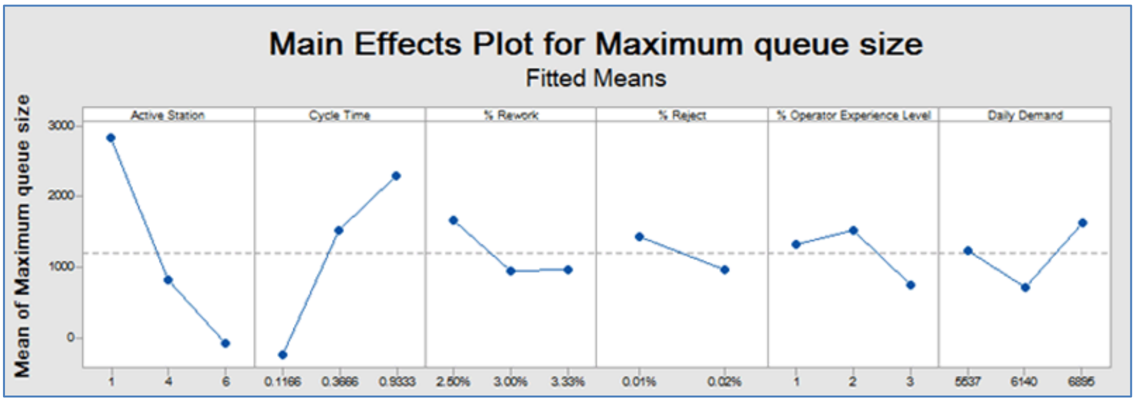

Figure 6-52 Main Effects Plot: MQS – Transfer Passengers' Security Screening

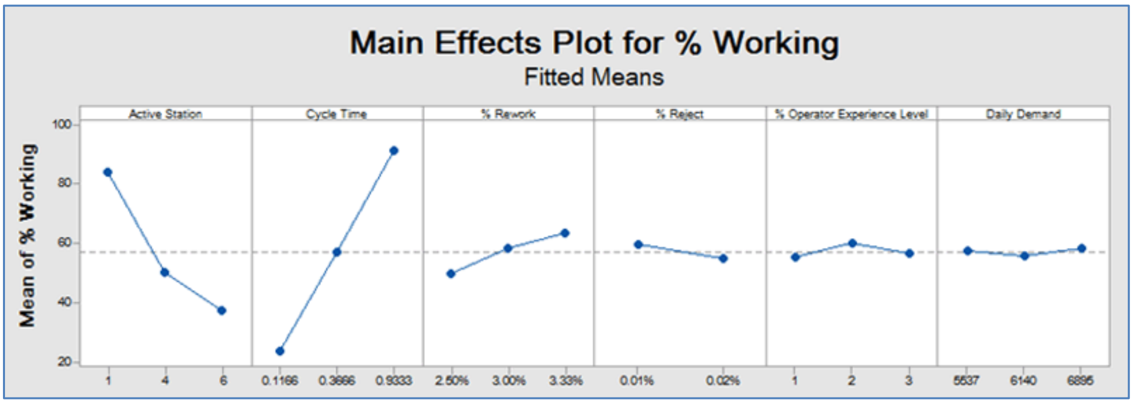

Figure 6-53 Main Effects Plot: Percentage Working Time – Transfer Passengers' Security Screening

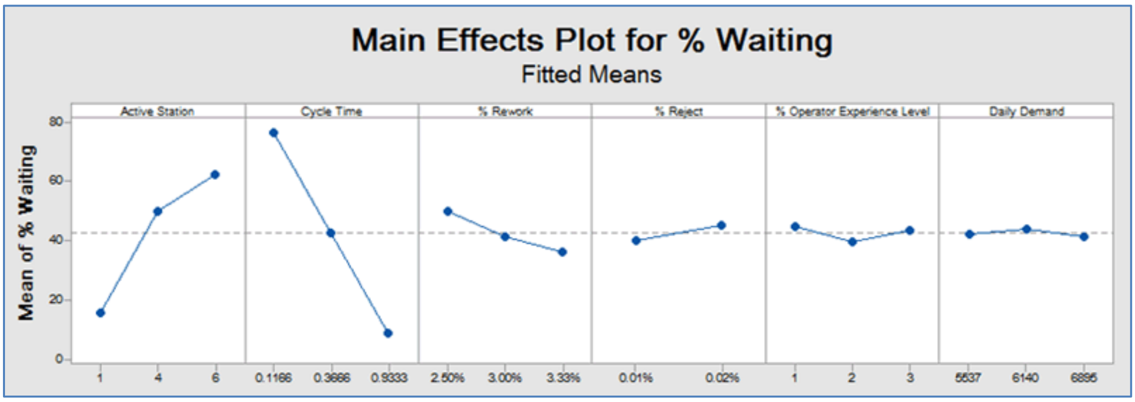

Figure 6-54 Main Effects Plot: Percentage Waiting Time – Transfer Passengers' Security Screening

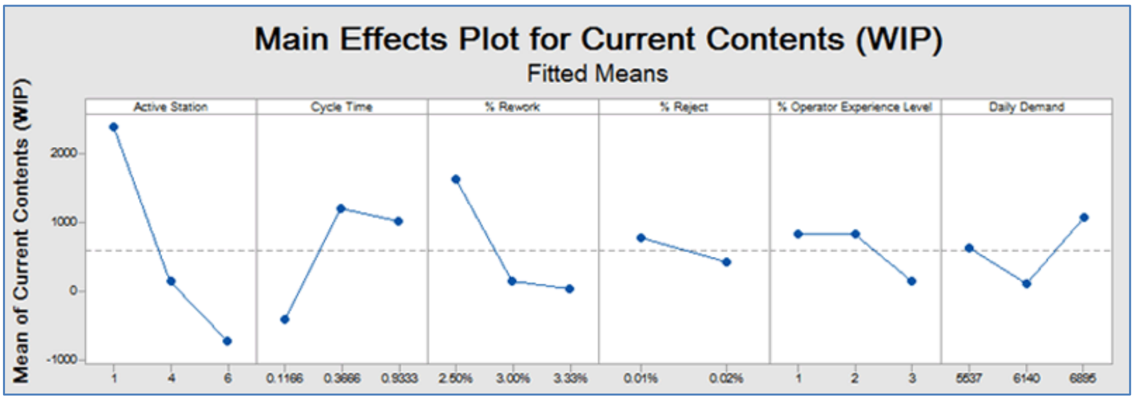

Figure 6-55 Main Effects Plot: WIP – Transfer Passengers' Security Screening

6.3.4 Simulation Model Results: Combined Processes

For the fifty-four statistical models tested for up to six dependent variables, and up to ten factor variables, a total of 137 *highly* statistically significant (HSS), 36 *very* statistically significant (VSS) and twenty-two statistically significant (SS) interactions are found (Table 6-2) though the models themselves accounted for a total of forty-nine at all levels of statistically significance. Of the remainder, most *highly* statistically significant interactions were for the number of 'Active Stations', followed those interactions between dependent variables and 'Cycle Time' of Processing stations.

Such is the overriding influence of national and international regulations on the detailed operations of each processing station a positive decision was made not to measure their operations. This was further supported in that the additional time collecting and processing data would have serious violated SMART objectives (Maylor and Blackmon 2005) which recommend that projects should all recognise that all data collection should be **s**pecific to the achievement of the project, **M**easurable using available methods and resources, **A**chievable, **R**ealistic within constraints of a strictly **T**ime-framed project especially as much additional time would be needed to develop simulation models and analyse results. While interactions between dependent variables and the factor 'Operator Experience' was found to be *highly* statistically significant in only five instances, observations and interviews with airport managers indicated that factor was capable of improving cycle time. Other factors such as percentages of 'rejects' and 'rework' were not sufficiently controllable as to relax standards in these areas could seriously infringe international rules and endanger passenger safety. In analysing of Taguchi factors and subsequent improvements to the simulation model, while to some extent imperfect, both adjustment of the number of Active Workstations and Operator Experience were selected as the two principal factors for improvement.

Table 6-2 Instances of Statistically Significant Interactions

Factor Variable	HSS	VSS	SS
All	137	36	22
Model	44	1	4
active_sta	41	0	1
c_time	36	6	1
r_work	2	11	8
r_ject	5	10	2
op_exper	5	0	0
daily_dmnd	4	8	5
c-gs8	0	0	1
c-gs3	0	0	0
c-gs1	0	0	0

A primary purpose of all Lean systems if to minimise the consumption or provision of resources which add no value to the product or service or which are wasted (Emiliani 1998). In any Lean system resource utilisation processes should be designed to keep up with demand and in ideal systems visual controls provide an immediate signal when of the operation condition of the process and when to apply change (Liker and Morgan 2006). Ideally, controls should be self-regulating and worker managed and these frequently involve Kanban-type systems.

6.4 Chapter Summary

The chapter shows the output of the simulation model using only standard rules. This researcher then produced graphic output using Minitab which was reported in this section and ANOVA was used in order to identify statistically significant dependent variables for use in developing simulation rules at each processing station. Each of these rules will table in the next Chapter.

Chapter 7 : Developing the Rule-Based Departure Process

7.1 Overview

Acting on the first stage analysis of these data presented in previous Chapter above a to develop series of improvement rules to take account of the two most important findings – the need to provide processing capacity where and when it is required in the capable of progressively increasing operating capacity using all underutilised resources, and rules which this research describes as ‘If Rules’ capable of giving the necessary visual signals to the workforce. The chapter presents briefly the rules implementation, development, and how the rules linked, applied and used to derive the improvement.

7.2 Implementation of the Rules

The rules have been applied to PDP DES model. The simulation has impeded function that allows inserting certain rules to the simulation. Simul8 allows the user write his/her own rules within the embedded function. The rules need to comply with certain rules. Simul8 also provides faculties to trace the rules interactions with other rules and identify any conflict or mistakes on the rules section 7.3.

7.2.1 Rules Development

The basis for developing rules lies in the original output when only default Simul8® settings applied. The output of Minitab® and especially ANOVA analysis contained in Section 6.4.1 for each part of the process, against defined independent variables, contains the basis of such rules. Nevertheless, external influences on the process which leave limited or no scope for improvement under Lean principles must be taken into account. The detailed operation of the check-in procedure is largely defined elsewhere and cannot be changed, except universally in response to external threats which may arise rapidly. So while cycle time improvement is *highly statistically significant* in the case of thirty-six processing elements (36 of 54 –Section 6.4.4) and *very statistically significant* or *statistically significant* in seven more (Table 6-2, Section 6.4.4), the opportunity to actually improve the sub-processes which contribute to cycle time is strictly limited for external reasons. One must look elsewhere to improve them. Table 6-2, shows that daily demand is statistically significant in seventeen cases, especially in check-in (Sections 6.4.1.1-5). Process designers can have little influence over this though it must be taken into account. This leaves a process designer again looking for factors which will influence cycle time and while it is not in itself *statistically significant* (Table 6-2) except in five cases, raising capability through operator experience provides the only realistic alternative to cycle time improvement. Table 6-2 gives further indications of factors which system improvers may use, the principal of which is the number of Active Stations which is highly significant in 41 of the fifty-four independent statistical evaluated.

Given the factors described section 8.3.2, developing a definitive answer which actually applies only to a 24 hr snapshot of a particular period would be misleading and potentially open to misinterpretation. The research here took an experimental, illustrative approach rather than fruitlessly seeking to prove a particular set of rules which would only apply to the necessarily limited circumstances in which research data was collected. These data has been collection from the airport authority by interviews, airport database. These data is needed to develop the rules based on the actual physical capacity of the terminal as an example.

In each case the rules were developed to confirm the basic principles derived from Taguchi experiments and their accompanying ANOVA analysis. Furthermore to illustrate that significant improvement could be achieved, by applying them in particular circumstances. The objective is to develop principles for changeable rules which may be flexibly applied by staff in-situ rather than saying 'one must slavishly apply rule X, or rule Y' in all circumstances.

7.2.2 Rules validation

The rules validated by checking the reality of the output for each station of the process by examining the results of the rules. The rules also changed to ensure the rules are working and have influence on the decision making of the process. The validation is needed to ensure that the rules have been written to serve the purpose of the rules. The ruled run several times within the simulation for known case studies to check the accuracy the validity of the rules.

7.3 Applying Expanded Simulation Rules

The rules are linked together through the package interaction embedded programming facilities. The link of the rules helps to improve the flow by reducing the passenger waiting as shown in Table 7-1. The main purpose of the rules is to reduce the waiting time by triggering the facilities needed such as number of stations needed and or the level skills of the stations operators. Figure 6-3 shows simulation model flow chart after scenario. It shows the rule link of developed rules and the simulation. The developed rules aims to improve the result based on the result before scenario.

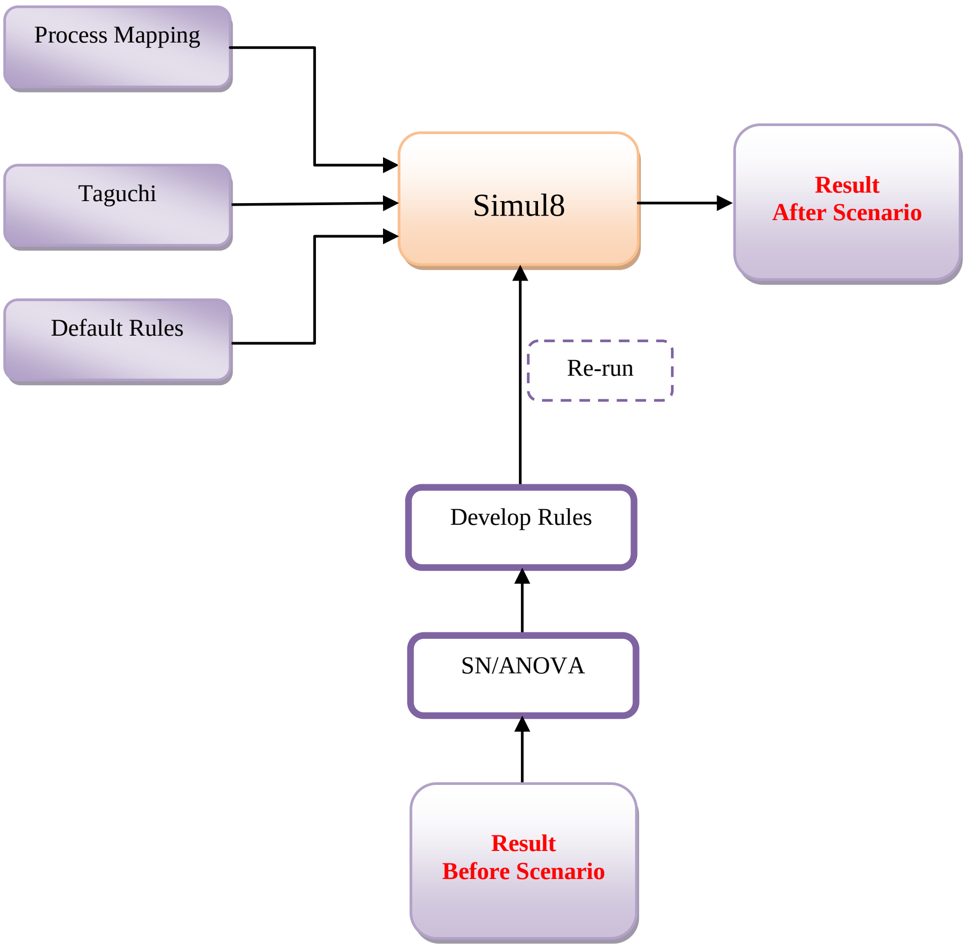

Figure 7-1 : Simulation model flow chart after scenario

In the case of check-in, for example, the objective was to prove that application of relatively simple rules can significantly improve passenger waiting times for Economy-

Class passengers. However, one cannot say that by generally applying rules contained in Tables 7-1 to 7-5 would achieve a median improvement of 65.95%. Nor can one say that the maximum median queuing-time is reduced by 20.58% (Table 8-1). This would be an incorrect interpretation of output data. The approach taken in this case is to show that, by considering unused or spare capacity which exists in all check-in facilities of every type and class, dramatic improvements could be achieved for the largest users of the traditional check-in, Economy-Class passengers. Some of the effects on First-Class passengers (Table 8-5) were simply ignored to illustrate that by exclusively considering optimisation to part of the entire process, undesirable degradation of cycle time would occur. This intends to illustrate that if too much emphasis is given to improving one part of the system, it may have an undesirable effect elsewhere.

In each case the approach was to examine the entire process elements of check-in, emigration, security and boarding respectively on a case-by-case basis, taking into account the prevailing circumstances to find how the most appropriate number of active process station may be brought into operation and how cycle time could best be improved. This is described in detail in Section 8.4.

CHECK-IN

Table 7-1 Simulation Rules: Improved Standard Economy-Class Check-in

3. Process Station	**Principal Aim**	Conditions: **Permanently Active Processing Stations**	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Standard Check-in Economy (CIE)	Progressively Increase Capacity	3	8	150	Disney
		NOTE: only used 6 counters CIES for check-in Economy to cope with demand in improvements			

The following rules trigger additional work stations (unless 'if rule' applies)	**'If' Rules**
a. Queuing-Time >=10 minutes	IF (active work stations >=5), THEN ((issue roster call so ALL CIE staff are graded Highly-Skilled) AND (Assign spare Medium-Skilled to self-check-in (CIES))) IF ((active work stations >7) AND (a >10 or b>10)), THEN (divert 50% queue to self-check-in (CIES))
b. Queue Length >=10 pax	
c. Queue Length >=55 pax	IF ((active work stations >7) AND (c>55)), THEN (divert 25% Economy-Class queue to Allocated Business-Class check-in (CIBC)) ,AND (CIBC Queue < 40)
d. Queue Length >=150 pax	IF ((CIE Queue Length = 150) AND (CIBC Overflow Queue= 40) AND (CIES queue=50)), THEN (Hold and manually reassign Economy Passengers)

Economy-Class Self-Check-in

Table 7-2 Simulation Rules: Improved Economy-Class Self-Check-in

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Self-Check-in Economy (CIES)	Progressively Increase Capacity	6	12	50	Disney
		NOTE: only used 6 counters and six counters for check-in Economy to cope with demand in improvements			
The following rules trigger additional work stations (unless 'if rule' applies)		**'If' Rules**			
a.	Queuing-Time >=10 minutes	IF ((active work stations >6) AND (a>10 or b>30)), THEN (divert queue to secondary queue) *In secondary queue check assist passengers to check-in online then send to Baggage Drop* AND (Assign spare Medium-Skilled to EBD) IF ((active work stations >7) AND (a>10 or b>30) AND (CIEBD Queue Length >=30)) THEN (Divert 33% Economy-Class Passengers to Business-Class Allocated Self-Check-in (CIBCS))			
b.	Queue Length >=30 pax				

Economy-Class Baggage Drop

Table 7-3 Simulation Rules: Improved Economy-Class Baggage Drop

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Check-in Economy Baggage Drop (CIEBD)	Progressively Increase Capacity	3	6	50	Disney
The following rules trigger additional work stations (unless 'if rule' applies)		**'If' Rules**			
a. Queuing-Time >=7 minutes		IF (active work stations >=4) AND (a>7 or b> 8)) , THEN ((issue roster call so ALL CIEBD staff are graded Highly-Skilled) AND (Assign spare Low-Skilled to Assigned Overflow in Business-Class (CIBC))			
b. Queue Length >=8pax					

Business-Class Standard Check-in

Table 7-4 Simulation Rules: Improved Business-Class Standard Check-in

<table>
<tr><th rowspan="2">Process Station</th><th rowspan="2">Principal Aim</th><th colspan="4">Conditions</th></tr>
<tr><th>Permanently Active Processing Stations</th><th>Total Processing Stations</th><th>Physical Queue Length (pax)</th><th>Queue Type</th></tr>
<tr><td>Standard Check-in Business-Class (CIBC)</td><td>Progressively Adjust Capacity to Maximise Use</td><td>1</td><td>8</td><td>10 x 8</td><td>Individual</td></tr>
<tr><td colspan="2">The following rules trigger additional work stations (unless ‘if rule’ applies)</td><td colspan="4">‘If’ Rules</td></tr>
<tr><td colspan="2">a. Queuing-Time >=5 minutes</td><td colspan="4">IF (active work stations >=3) AND (a>5 or b>8)), THEN ((issue roster call so ALL CIBC staff are graded Highly-Skilled) AND (Assign spare Medium-Skilled to Assigned Economy Self-Check-in CIES Overflow in Business-Class (CIBCS))</td></tr>
<tr><td colspan="2">b. Queue Length >=8pax</td><td colspan="4">IF (active work stations >8), THEN (reassign 2 First-Class-Check-in (CIFC) to Business-Class-Check-in (CIBC))</td></tr>
</table>

First-Class Standard Check-in

Table 7-5 Simulation Rules: Improved First-Class Standard Check-in

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Standard Check-in First-Class (CIFC)	Progressively Adjust Capacity to Maximise Use	1	5	10 x 5	Individual
		1) Note up to three counters needed to process F/B *2) At peak time two stations assigned to Business-Class*			
The following rules trigger additional work stations (unless 'if rule' applies)		**'If' Rules**			
a. Queuing-Time >=5 minutes		IF (active work stations >=2), AND (a>5 or b>2) THEN ((issue roster call so ALL CIFC staff are graded Highly-Skilled) AND (Assign spare Medium-Skilled to Assigned Business-Class CIBC Overflow in First-Class (CIFC))			
b. Queue Length >=2 pax		IF (active work stations >4), THEN (reassign 2 CIFC Stations to Business-Class (CIBC))			

Economy-Class Emigration

EMIGRATION

Table 7-6 Simulation Rules: Improved Economy Emigration

<table>
<tr><th rowspan="2">Process Station</th><th rowspan="2">Principal Aim</th><th colspan="4">Conditions</th></tr>
<tr><th>Permanently Active Processing Stations</th><th>Total Processing Stations</th><th>Physical Queue Length (pax)</th><th>Queue Type</th></tr>
<tr><td>Emigration Economy (EE)</td><td>Progressively Increase Capacity</td><td>2</td><td>8</td><td>150</td><td>Disney</td></tr>
<tr><th colspan="2">The following rules trigger additional work stations (unless ‘if rule’ applies)</th><th colspan="4">‘If’ Rules</th></tr>
<tr><td colspan="2">a. Queuing-Time >=5 minutes</td><td colspan="4" rowspan="3">IF (active work stations >=6), AND (a >5 or b >8) THEN (issue roster call so ALL EE staff are graded Highly-Skilled) AND (IF (active work stations >7), AND (c>80) THEN (reassign 2 EFB to EE issue roster call))</td></tr>
<tr><td colspan="2">b. Queue Length >=8pax</td></tr>
<tr><td colspan="2">c. Queue Length >= 80pax</td></tr>
</table>

First & Business-Class Emigration

Table 7-7 Simulation Rules: Improved First/Business-Class Emigration

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Emigration First/Business (EFB)	Progressively Adjust Capacity to Maximise Use	1	4	10x4	Individual
The following rules trigger additional work stations (unless 'if rule' applies)		**'If' Rules**			
a.	Queuing-Time >=5 minutes	IF (active work stations >=2), AND (a>5 or b>4) THEN (issue roster call so ALL EFB staff are graded Medium-Skilled)			
b.	Queue Length >=4pax	IF (2 active workstations assigned to EE), THEN (issue roster call so ALL EFB staff are graded Highly-Skilled)			

Economy-Class Security

SECURITY

Table 7-8 Simulation Rules: Improved Economy-Class Security

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	**Total Processing Stations**	**Physical Queue Length (pax)**	**Queue Type**
Security Economy (SE)	Progressively Increase Capacity	1	2	100	Disney
The following rules trigger additional work stations (unless 'if rule' applies)		**'If' Rules**			
a. Queuing-Time >=5 minutes		IF (active work stations =2 AND b>=20 or a >=5), THEN (issue roster call so ALL SE staff are graded Highly-Skilled			
		IF (All SE are actually Highly-Skilled), THEN (reassign 1 Station to Joint Economy/First/Business-Class)			
b. Queue Length >=20pax					

First& Business-Class Security

Table 7-9 Simulation Rules: Improved First/Business-Class Security

<table>
<tr><th rowspan="2">Process Station</th><th rowspan="2">Principal Aim</th><th colspan="4">Conditions</th></tr>
<tr><th>Permanently Active Processing Stations</th><th>Total Processing Stations</th><th>Physical Queue Length (pax)</th><th>Queue Type</th></tr>
<tr><td rowspan="2">Security First/Business (SFB)</td><td rowspan="2">Progressively Adjust Capacity to Maximise Use</td><td>1</td><td>+1 shared with SE</td><td rowspan="2">10</td><td rowspan="2">Individual</td></tr>
<tr><td colspan="2">At peak times (defined by 6 pax) ALL SFB assigned are highly-skilled</td></tr>
<tr><th colspan="2">The following rules trigger additional work stations (unless ‘if rule’ applies)</th><th colspan="4">‘If’ Rules</th></tr>
<tr><td colspan="2">a. Queuing-Time >=5 minutes</td><td colspan="4" rowspan="2">IF ((b>=6, or a>=5,) AND (No Second Queue in ES)), THEN ((Open one Station to Joint Economy/First/Business-Class) AND (Assign Highly-Skilled operator) AND (priority assign 50% F/BC passengers to shared queue with EC)) OR ((a>5, b>=6) AND (Second Queue in EC)), THEN (priority assign 50% F/BC passengers to shared queue with EC) AND (IF ((Medium-Skilled operator in Shared Queue) THEN (roster Highly-Skilled operator to shared queue))</td></tr>
<tr><td colspan="2">b. Queue Length >=6 pax</td></tr>
</table>

Transfer Passenger Security

Table 7-10 Simulation Rules: Improved Transfer Passenger Security

<table>
<tr><th rowspan="2">Process Station</th><th rowspan="2">Principal Aim</th><th colspan="4">Conditions</th></tr>
<tr><th>Permanently Active Processing Stations</th><th>Total Processing Stations</th><th>Physical Queue Length (pax)</th><th>Queue Type</th></tr>
<tr><td>Security Transfer Passenger (STP)</td><td>Progressively Increase Capacity</td><td>1</td><td>6</td><td>100</td><td>Disney</td></tr>
<tr><td colspan="2">The following rules trigger additional work stations (unless ‘if rule’ applies)</td><td colspan="4">‘If’ Rules</td></tr>
<tr><td colspan="2">a. Queuing-Time >=5 minutes</td><td colspan="4">IF (active work stations =2), THEN issue roster call so ALL STR staff are graded Medium-Skilled</td></tr>
<tr><td colspan="2">b. Queue Length >=10pax (4 machines needed)</td><td colspan="4" rowspan="2">IF ((active work stations >=5), AND (c>=20or a>=5)), THEN (issue roster call so ALL STR staff are graded Highly-Skilled)</td></tr>
<tr><td colspan="2">c. Queue Length >= 20pax</td></tr>
</table>

Boarding Desk (All Classes)

Table 7-11 Simulation Rules: Boarding Desk

Process Station	Principal Aim	Conditions			
		Permanently Active Processing Stations	Total Processing Stations	Physical Queue Length (pax)	Queue Type
Boarding Desks (SFB)	Unchanged				
The following rules trigger additional work stations (unless 'if rule' applies)		'If' Rules			
No need to join and share stations					

Each of the rules contained in Tables 7-1 to 7-11 which generated additional work stations from existing capacity and their associated 'If' Rules was incorporated into the simulation model and the results in Section 7.4 generated

7.4 Data for Improved Passenger Flow

This section gives the principal data for each individual process in the passenger departure process when improvement rules have been applied.

A complete detailed dataset is in Confidential Appendix B 15

The simulation model produces flows of passenger on a daily (24 hr) basis taking into account daily fluctuations/peaks in demand. Originating passengers in the following Tables 7-12 to 7-27 cover numbers of passengers who report to various check-in desks, including self-service and baggage drop but do not include the approximately 6% of passengers who use off-site check-in facilities such as city centre baggage drops and check-ins

7.4.1 Standard Economy-Class Check-in

Table 7-12 shows improved queuing characteristics throughout the 24-hour period. Most important of these from the project's perspective, are Mean and Maximum Queuing Times which are key measures of improvement. Passengers who must report to a check-in after waiting in a Disney queue are those described in the line 'Minimum (non-zero) Queuing-Time. The same is true of waiting in line for 'Mean (non-zero) Queuing-Time and MQS. Throughput in Table 7-12 only includes originating passengers who do not use means of check-in other than the 'traditional' Economy check-in stations. Numbers of originating passengers may or may not have previously confirmed their flight online through the internet.

For the standard economy-class check-in queuing time has been improved by using the rules presented in Table 7-1. The rules set a limit queuing time of 10 minutes at which more experience and skilled staff replaced less experienced staff. Less experience staff then can be used to other duties in the process such as directing passengers. The rules also triggered number of working stations when the process working at capacity of 50% of passengers were redirected and assisted at self-check-in. The rules also provides a trigger when the fifty-five passengers which diver the passenger to a Disney queue adjacent to business class. The use of the rules to improve the passengers queuing time is presented in more details on 8.4.1.

Table 7-12 Economy Check-in: Queues and Throughput

Queuing	Mean	**Median**	**Max**	**Min**	**Std. Dev.**	
Mean Queue Size	3.92	0.73	11	0	4.5710	pax
MQS	42.15	26	81	17	24.5587	pax
Minimum (Non-zero) Queuing-Time	00:00	00:00	00:02	00:00	00:00.491	mm:ss
Mean Queuing-Time	01:14	00:17	03:19	00:07	01:23.070	mm:ss
Mean (Non-zero) Queuing-Time	02:00	01:26	03:42	00:58	01:08.754	mm:ss
Maximum Queuing-Time	09:47	08:08	15:20	06:11	02:49.437	mm:ss
Throughput	**4063**	**4091**	**4857**	**3515**	**514.7718**	**pax**

Table 7-13 presents the results of throughput of various check-in desks during a full twenty-four hour period while Table 7-15 presents their mean use as a percentage of their working capacity though expressed by the simulation program as various sized (8:3:1) groups of passengers rather than individuals.

Table 7-13 Economy Check-in: Throughput in Groups

Throughput in Groups	Desk	**Mean**	**Median**	**Max**	**Min**	**Std. Dev.**	
	Desk 1	226.56	221	293	175	36.7971	groups
	Desk 2	184.00	184	236	139	30.3771	groups
	Desk 3	178.96	188	234	132	33.1181	groups
	Desk 4	144.85	140	195	102	31.2800	groups
	Desk 5	148.74	142	204	102	32.4969	groups
	Desk 6	132.00	124	184	93	24.4210	groups
	Desk 7	117.37	114	171	86	24.0227	groups
	Desk 8	109.78	101	165	87	21.8831	groups
	All	**1242.26**	**1145**	**1543**	**1013**	**181.5249**	groups

The three permanently-open check-in desks (D1, D2 & D3) have a significantly higher throughput over the twenty-four hour period than other desks with Desk 1 being the most favoured by passengers which reflects field observations, though as may be expected the reserve desks (have a high usage because they are activated on an ‘as required’ basis rather than standing idle for any appreciable time. As Table 7-14 shows, there is an appreciable drop-off of usage for reserve desk 5 which is brought into action during periods of medium and peak activity.

Table 7-14 Economy Check-in: Mean Use of Processing Stations

Mean Use %	Desk	Mean	Median	Min	Std. Dev.
	Desk 1	55.97	56.27	65.30	45.16
	Desk 2	41.47	40.64	46.54	33.35
	Desk 3	41.23	42.03	46.20	32.30
	Desk 4	61.24	68.77	91.35	24.31
	Desk 5	60.44	47.59	92.05	27.09
	Desk 6	64.22	79.16	93.78	31.26
	Desk 7	71.45	85.10	97.92	26.40
	Desk 8	78.30	90.62	97.92	31.61
	All [%]	31.90	31.92	97.92	24.31

7.4.2 Economy-Class Self-Check-in

Table 7-15 Economy Self Check-in: Queuing and Throughput

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean queue size	188.85	186	222	159	26.4717	groups
Throughput - All	**978.1**	**991**	**1198**	**788**	**118.9964**	pax

Different characteristics of usage mean that queuing (Table 7-15) is displayed differently from other Active Stations such as in the earlier Table 7-12, and queuing data output by the simulation program gives an inaccurate representation of the mean queue size. Nevertheless, Table 7-16 shows that each self-check-in station is working significantly below capacity and this supports the proposition that queues are unlikely to build up to the extent shown overleaf in Table 7-17.

Table 7-16 Economy Self Check-in: Mean Working of Each Self-Check-in Station as a Percentage of Its Working Capacity

Working %	Desk	Mean	Median	Max	Min	Std. Dev.
		%	%	%	%	%
	Desk 1	54.64	36.47	96.53	22.58	29.6281
	Desk 2	61.11	39.60	98.99	22.23	31.1310
	Desk 3	60.63	38.21	98.26	24.31	31.1832
	Desk 4	53.57	35.43	97.60	21.54	30.5608
	Desk 5	53.48	33.00	97.95	23.62	30.4865
	Desk 6	48.51	33.69	98.30	22.58	28.1269
	Desk 7	11.00	11.12	13.20	8.68	1.8802
	Desk 8	11.81	9.38	18.06	7.99	4.5422
	Desk 9	11.12	9.73	14.24	9.38	2.2572
	Desk 10	13.43	13.20	16.67	10.42	2.6063
	Desk 11	15.63	15.28	18.76	12.85	2.4694
	Desk 12	20.38	21.88	22.58	16.67	2.6855
	All [%]	**34.61**	**22.58**	**98.99**	**7.9890**	**29.8346**

Table 7-17 Economy Self Check-in: Throughput in Pax

Throughput in Pax	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	83	83	99	67	10.4440	pax
	Desk 2	78	77	96	38	13.1725	pax
	Desk 3	76	75	95	35	17.4354	pax
	Desk 4	76	78	96	38	16.3965	pax
	Desk 5	77	78	96	36	17.6679	pax
	Desk 6	75	82	95	35	19.5504	pax
	Desk 7	64	64	75	52	9.5716	pax
	Desk 8	76	74	93	60	13.7813	pax
	Desk 9	68	63	82	60	9.9267	pax
	Desk 10	74	72	92	58	14.2181	pax
	Desk 11	97	95	111	84	11.2967	pax
	Desk 12	114	113	129	100	12.0862	pax
	All	**956.9**	**973**	**1142**	**762**	**113.9505**	pax

Table 7-18 Economy Self-Check-in: Mean Use of Processing Stations

Mean Use %	Desk	Mean	Median	Min	Std. Dev.
	Desk 1	54.64	36.47	96.53	22.58
	Desk 2	61.11	39.60	98.99	22.23
	Desk 3	60.63	38.21	98.26	24.31
	Desk 4	53.57	35.43	97.60	21.54
	Desk 5	53.48	33.00	97.95	23.62
	Desk 6	48.51	33.69	98.30	22.58
	Desk 7	11.00	11.12	13.20	8.68
	Desk 8	11.81	9.38	18.06	7.99
	Desk 9	11.12	9.73	14.24	9.38
	Desk 10	13.43	13.20	16.67	10.42
	Desk 11	15.63	15.28	18.76	12.85
	Desk 12	20.38	21.88	22.58	16.67
	All [%]	**34.61**	**22.58**	**98.99**	**7.9890**

7.4.3 Economy-Class Baggage Drop

Table 7-19 Economy Baggage Drop: Queues and Throughput

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean Queue Size	0.11	0.1	0.2	0.0	0.0568	pax
MQS	10.78	11	13	7	1.4500	pax
Minimum (Non-zero) Queuing-Time	00:05	00:03	00:28	00:00	00:06.375	mm:ss
Mean Queuing-Time	00:09	00:08	00:18	00:00	00:04.599	mm:ss
Mean (Non-zero) Queuing-Time	01:24	01:27	02:27	00:24	00:34.693	mm:ss
Maximum Queuing-Time	04:01	04:16	07:00	00:50	01:37.364	mm:ss
Throughput	**1097**	**1083**	**1305**	**921**	**153.1172**	**pax**

For Baggage Drop, three permanently Active Stations (D1, D2 & D3) are responsible for most throughput (Table 7-20) though overall mean use (Table 7-21) suggests there is spare capacity still to be exploited if necessary for standard check-in operations.

Table 7-20 Economy Baggage Drop: Throughput in Groups

Throughput in Groups	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	86.44	85	110	65	12.8642	groups
	Desk 2	115.93	112	167	90	17.9313	groups
	Desk 3	165.07	155	235	104	37.0280	groups
	Desk 4	46.89	55.00	85.00	0.00	24.9096	groups
	Desk 5	40.04	36.00	91.00	0.00	29.0563	groups
	Desk 6	7.07	0.00	40.00	0.00	11.3406	groups
	All	**461.44**	**469**	**583**	**361**	**67.6065**	groups

Table 7-21 Economy Baggage Drop: Mean Use of Processing Stations

Mean Use%	Desk	Mean	Median	Min	Std. Dev.
	Desk 1	23.04	23.24	31.57	12.16
	Desk 2	21.85	21.19	30.91	17.37
	Desk 3	28.49	28.14	37.48	22.93
	Desk 4	22.82	14.24	91.66	0.00
	Desk 5	22.87	10.07	91.32	0.00
	Desk 6	19.29	0.00	94.79	0.00
	All(%)	**23.06**	**21.36**	**94.79**	**0.00**

7.4.4 Business-Class Standard Check-in

Table 7-22 Business-Class Check-in: Queues and Throughput

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean queue size	0.10	0	0	0	0.0739	pax
MQS	10.74	7	28	5	6.7687	pax
Mean Queuing-Time	00:13	00:13	00:26	00:07	00:04.513	mm:ss
Mean (non-zero) Queuing-Time	01:22	01:20	01:50	01:01	00:12.158	mm:ss
Maximum Queuing-Time	04:38	04:03	08:53	03:27	01:23.117	mm:ss
Throughput	**600**	**509**	**995**	**417**	**203.4170**	pax

Table 7-23 Business-Class Check-in: Throughput in Groups

Throughput in Groups	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	246.85	244	293	216	21.7710	item
	Desk 2	106.00	109	137	71	18.8353	item
	Desk 3	63.48	65	102	21	21.8445	item
	Desk 4	32.48	30	78	0	23.7153	item
	Desk 5	17.04	0	62	0	23.1989	item
	Desk 6	14.48	0	65	0	23.1157	item
	Desk 7	14.52	0	65	0	23.5525	item
	Desk 8	14.37	0	67	0	22.7768	item
	All	**509.22**	**476**	**686**	**381**	**114.04**	item

Most throughput (Table 7-23) is concentrated in just two desks (D1 & D2) with D3 being used for medium peak periods. The remaining desks (D4-8) have low utilisation even though, under improvement rules (Table 7-4) some capacity is used for diverted Economy-Class passengers. Even such diversion does not result in excessive queues developing (Table 7-22) while use of Active Stations remains low or very low (Table 7-24).

Table 7-24 Business-Class Check-in: Mean Use of Processing Stations

Mean Use %	Desk	**Mean**	**Median**	**Min**	**Std. Dev.**
	Desk 1	29.58	28.83	33.66	26.05
	Desk 2	17.90	14.90	29.52	8.34
	Desk 3	18.43	10.73	92.71	5.21
	Desk 4	14.93	4.86	90.62	0.00
	Desk 5	3.90	0.00	23.62	0.00
	Desk 6	4.90	0.00	23.97	0.00
	Desk 7	4.21	0.00	26.05	0.00
	Desk 8	2.80	0.00	23.62	0.00
	All[%]	12.08	6.95	92.71	0.00

7.4.5 First-Class Standard Check-in

Table 7-25 First-Class Check-in: Queues and Throughput

Queuing	**Mean**	**Median**	**Max**	**Min**	**Std. Dev.**	
Mean Queue Size	0.04	0	0	0	0.0273	groups
MQS	6.04	8	8	2	2.8350	groups
Minimum (Non-zero) Queuing-Time	00:03	00:00	01:13	00:00	00:14.104	mm:ss
Mean Queuing-Time	00:22	00:25	00:42	00:00	00:17.539	mm:ss
Mean (Non-zero) Queuing-Time	02:51	03:28	05:09	00:02	02:00.242	mm:ss
Maximum Queuing-Time	06:09	07:17	11:08	00:03	04:16.168	mm:ss
Throughput	**123.00**	**120**	**153**	**101**	**19.4620**	**pax**

Under improvement rules (Table 7-5), First-Class check-in stations act as overflows for Business-Class passengers. Despite this queues remain low in a way desirable for First-Class passengers even at peak times (Table 7-25). Given careful management of the overflow from Business-Class, this excess capacity (Table7-24) will ensure First-Class passengers retain zero queuing-time.

Table 7-26 First-Class Check-in: Mean Use of Processing Stations

Mean Use %	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	15.00	14.90	17.33	13.16	1.11	%
	Desk 2	3.79	4.17	5.21	1.39	1.08	%
	Desk 3	2.29	2.78	3.82	0.35	1.14	%
Throughput	**All**	**7.03**	**4.17**	**17.33**	**0.35**	**5.81166**	%

Table 7-27 First-Class Check-in: Throughput in Pax

Throughput in pax	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	74.04	70	91	65	8.4146	pax
	Desk 2	18.74	18	24	14	2.7258	pax
	Desk 3	15.15	17	24	5	6.2123	pax
Total (incl. B/C pax)	**All**	**108**	**105**	**128**	**92**	**14.3953**	pax

7.4.6 Economy-Class Emigration

Table 7-28 Economy Emigration: Queues and Throughput

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean Queue Size	0.63	1	1	0	0.2532	pax
MQS	29.96	30	44	17	6.5544	pax
Minimum (Non-zero) Queuing-Time	00:00	00:00	00:00	00:00	00:00.045	mm:ss
Mean Queuing-Time	00:09	00:09	00:17	00:05	00:02.904	mm:ss
Mean (Non-zero) Queuing-Time	00:34	00:35	00:40	00:27	00:03.728	mm:ss
Maximum Queuing-Time	03:35	03:26	05:24	02:42	00:43.183	mm:ss
Throughput	**5991.00**	**5927**	**7057**	**5128**	**588.7934**	pax

Table 7-29 Economy Emigration: Throughput in Groups

Throughput in groups	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	771.19	774	887	691	58.8179	groups
	Desk 2	591.56	597	671	518	43.2420	groups
	Desk 3	408.67	399	523	338	46.0025	groups
	Desk 4	344.15	332	494	272	45.8918	groups
	Desk 5	298.56	298	355	232	34.4666	groups
	Desk 6	264.22	267	337	199	39.4757	groups
	Desk 7	227.41	229	315	147	46.4959	groups
	Desk 8	194.52	191	279	108	49.0536	groups
	All	**3100.26**	**3046**	**3759**	**2511**	**338.5585**	groups

Table 7-30 Economy Emigration: Mean Use of Processing Stations

Mean Use %	Desk	Mean	Median	Min	Std. Dev.
	Desk 1	64.35	65.27	68.74	56.96
	Desk 2	47.77	47.20	55.92	39.60
	Desk 3	66.55	76.76	83.68	28.83
	Desk 4	60.05	67.70	90.66	24.66
	Desk 5	46.06	38.17	88.19	19.45
	Desk 6	46.65	35.78	88.54	14.59
	Desk 7	47.67	34.39	85.06	10.42
	Desk 8	54.18	67.70	88.54	10.42
	All[%]	**54.16**	**60.44**	**90.66**	**10.42**

7.4.7 First & Business-Class Emigration

Table 7-31 First & Business-Class Emigration: Queues

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean queue size	0.03	0	0	0	0.0445	pax
MQS	8.63	7	21	3	4.2891	pax
Minimum (non-zero) Queuing-Time	00:00	00:00	00:00	00:00	00:00.000	mm:ss
Mean Queuing-Time	00:02	00:01	00:06	00:00	00:01.723	mm:ss
Mean (non-zero) Queuing-Time	00:32	00:23	01:45	00:09	00:26.997	mm:ss
Maximum Queuing-Time	03:37	02:04	08:51	00:21	03:07.566	mm:ss

Table 7-32 First & Business-Class Emigration: Throughput in Pax

Throughput in pax	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	429.41	430	527	380	41.5704	pax
	Desk 2	75.67	51	152	30	41.4794	pax
	Desk 3	60.81	44	145	0	44.8485	pax
	Desk 4	45.07	35	142	0	47.7179	pax
	All	**611**	**575**	**802**	**469**	**126.1938**	pax

Table 7-33 First & Business-Class Emigration: Mean Use of Processing Stations

Mean Use %	Desk	Mean	Median	Min	Std. Dev.
	Desk 1	17.57	17.02	21.85	12.85
	Desk 2	14.16	3.47	90.27	1.39
	Desk 3	25.86	2.78	89.58	0.00
	Desk 4	26.72	2.08	89.58	0.00
	All[%]	**21.08**	**11.12**	**90.27**	**0.00**

7.4.8 Economy-Class Security

Table 7-34 Economy Security: Queues

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean queue size	0.74	1	1	0	0.2140	pax
MQS	25.37	25	38	16	5.3648	pax
Minimum (non-zero) Queuing-Time	00:00	00:00	00:00	00:00	00:00.005	mins.
Mean Queuing-Time	00:10	00:11	00:15	00:07	00:02.418	mins.
Mean (non-zero) Queuing-Time	00:16	00:16	00:21	00:11	00:02.913	mins.
Maximum Queuing-Time	01:53	01:49	03:20	01:13	00:29.486	mins.

Table 7-35 Economy Security: Throughput in Pax

Throughput in pax	Desk	Mean	Median	Max	Min	Std. Dev.	
	Desk 1	3291.22	3231	3924	2713	331.9052	pax
	Desk 2	2688.44	2657	3302	2308	300.3798	pax
	All	**5979.66**	**5873**	**6990**	**5069**	**585.2139**	pax

Table 7-36 Economy Security: Mean use of Processing Stations

Mean Use %	Desk	Mean	Median	Max	Min	Std. Dev.
	Desk 1	27.35	26.75	33.35	21.19	3.0651
	Desk 2	21.48	21.54	27.41	17.02	2.7820
	All[%]	**24.41**	**24.64**	**33.35**	**17.02**	**4.1475**

7.4.9 First & Business-Class Security

Table 7-37 First & Business-Class Security: Queues and Throughput

Queuing	Mean	Median	Max	Min	Std. Dev.	
Mean Queue Size	0.06	0	0	0	0.0475	pax
MQS	11.70	10	22	5	4.1585	pax
Minimum (Non-zero) Queuing-Time	00:00	00:00	00:01	00:00	00:00.259	mm:ss
Mean Queuing-Time	00:06	00:05	00:15	00:03	00:03.484	mm:ss
Mean (Non-zero) Queuing-Time	00:22	00:21	00:31	00:15	00:04.569	mm:ss
Maximum Queuing-Time	01:32	01:26	02:31	00:58	00:19.470	mm:ss
Throughput	**752**	**652**	**1192**	**534**	**231.4285**	pax

7.4.10 Transfer Passenger Security

Table 7-38 Transfer Passenger Security: Queues and Throughput

Queuing	**Mean**	**Median**	**Max**	**Min**	**Std. Dev.**	
Mean queue size	0.14	0	0	0	0.0426	pax
MQS	12.33	12	13	12	0.4804	pax
Minimum (non-zero) Queuing-Time	00:00	00:00	00:00	00:00	00:00.020	mins.
Mean Queuing-Time	00:02	00:02	00:03	00:01	00:00.442	mins.
Mean (non-zero) Queuing-Time	00:17	00:15	00:26	00:11	00:04.301	mins.
Maximum Queuing-Time	02:33	02:52	03:42	01:34	00:39.355	mins.

Table 7-39 Transfer Passenger Security: Throughput in Pax

Throughput in pax	Desk	**Mean**	**Median**	**Max**	**Min**	**Std. Dev.**
	Desk 1	1690.81	1688	1829	1525	102.9854
	Desk 2	1280.11	1273	1413	1120	100.6706
	Desk 3	1061.15	1078	1305	815	142.9577
	Desk 4	983.33	961	1223	802	116.0809
	Desk 5	896.30	928	1131	737	94.2104
	Desk 6	278.96	55	932	0	342.3029
	All	**6190.67**	**6140**	**6895**	**5537**	566.1406

Table 7-40 Transfer Passenger Security: Mean use of Processing Stations

Mean use %	Desk	**Mean**	**Median**	**Max**	**Min**	**Std. Dev.**
	Desk 1	43.95	44.11	48.98	36.82	2.9901
	Desk 2	34.01	34.04	38.90	28.48	2.9676
	Desk 3	27.74	27.79	35.43	17.37	4.1734
	Desk 4	25.72	25.01	33.35	20.49	3.3930
	Desk 5	23.75	23.97	29.52	19.10	3.1308
	Desk 6	7.58	1.74	24.66	0.00	9.1158
	All [%]	27.12	26.92	48.98	0.00	12.0140

7.4.11 Simulated Passenger Movement

Table 7-41 Passenger Movement

Passenger Movement in pax	**mean**	**median**	**max**	**min**	**Std. Dev**
Take-off	12,675	12,519	14,184	11,061	906.3329
Boarding	12,159	12,093	14,280	10,324	1119.0767
Security - Transfer Passengers	6,191	6,140	6,895	5,537	566.1406
Security - First/Business	752	652	1,192	534	231.4285
Security - Economy	5,980	5,873	6,990	5,069	585.2139
Security Total	12,922	12,989	14,915	11,162	979.5387
Security Originating (F/BC/E)	6,731	6,522	8,020	5,625	792.6231
Emigration - First/Business	756	654	1,199	537	232.7233
Emigration - Economy	5,991	5,927	7,057	5,128	588.7934
Emigration - Originating (F/BC/E)	6,747	6,581	8,024	5,686	795.1074
Check-in - First	98	95	113	87	11.0801
Check-in - Business	600	509	995	417	203.4170
Check-in - Economy Self-Service	492	481	582	414	70.3677
Check-in - Economy Baggage Drop	1,097	1,083	1,305	921	153.1172
Check-in - Economy	4,063	4,091	4,857	3,515	514.7718
Check-in - All Economy	5,653	5,588	6,639	4,850	546.7921
Check-in - All Originating	6,351	6,198	7,571	5,380	735.1004

7.5 Chapter Summary

The chapter presented the rules that have been developed in this research implementation, development, and how the rules linked, applied and used to derive the improvement in the passenger departure flow. The rules developed in order to take account of the two most important findings, and rules which this research describes as ‘If Rules’ capable of giving the necessary visual signals to the workforce

Chapter 8 : Development of Knowledge Base to Improve the Process of Passenger Flow

8.1 Overview

This Chapter discusses the results described in Chapter 7 and gives proposals for the improvement of the departure process using Lean principles. This will involve summarising the necessary steps in this and similar improvement projects and how the identified improved performance measures can be put in place. It will describe a useful practical method for improving the passenger process in terminal 3 of Abu Dhabi Airport. The Chapter also identifies limitations in this research. This chapter will also show how the research aim and objectives have been fully achieved during this project.

8.2 Fulfilling Research Aim and Objectives

The main research aim and objectives were set out in Chapter 1 as follows:

The main aim of this research is to develop a single methodology to reduce the waiting time at processing stations and improve quality of service (QoS) so that passengers spend more time in duty free at the departing passengers at Abu Dhabi international airport. A single methodology means that the proposed approach is applicable (without any changes) to each element (i.e. group of processing station, such as check-in, immigration, etc.) of the passenger departure process (PDP).

Research objectives

1. Develop process mappings to understand the logical process flow and identify the factors causing the variability.
2. Design experiments using the factors influencing the waiting time and QoS for PDP flow and develop discrete event simulation (DES) model from the process mappings to identify mixed levels of variability in order to address the airport operational problems affecting the PDP, which influence the applicability of Lean principles about the efficient flow of passengers.
3. Analyse the simulation results based on default settings to identify cause and effect influencing the passenger waiting times and QoS.
4. Develop the rules to improve the PDP flow based on the identified root cause/s.

5. Apply rule-based approach to the PDP flow to improve waiting time regardless of the changing condition during complex combination of passenger flow at various times.

The following parts of this chapter summarise how the aim and the research objectives were fully met despite encountering a number of barriers set out in 8.3 below. Chapter 4 and 5 gives full details of how the third objective was met while a section 4.6 (step 8) sections 6.3. Section 4.6 (steps 7and 6) section 5.4 and 5.5 describes fully how the research met the second objective. Section 4.6 (step 5), section 5.3and section 5.6 describe how objective one has been met .The forth objective described and met in section 4.6 (step 9), section 7.1 and section 7.2 .In the case of the fifth objective, Section 7.3 demonstrates how by applying a relatively straightforward rule-based methodology individual elements of the passenger departure process may be improved regardless of the changing conditions during complex combinations of passenger flow at various times. These are summarised later in this chapter, with a discussion of results in section in 8.4 and used to develop SERVICE principles which are described in section 8.12 of the final chapter. Thus, by meeting these objectives in their entirety the project met its research aim fully.

8.3 Simulating Lean Processes in Airport Departure

8.3.1 Barriers to Lean

The Lean philosophy was developed originally in manufacturing by James Womack (Womack, et al. 1990) and Peter Hines (Hines, et al. 2004, Hines, et al. 1999, Hines and Rich 1997) and has been extended into the service sector (Bicheno 2008, Bowen and Youngdahl 1998, T.P. and Mcclean 2010). However, airport operations do not fit easily into either the Lean manufacturing or Lean service model for several reasons, many of which have been discussed earlier in this research (for example Sections 3.6 and 6.2.1). One might summarise these as follows:

- The departure process is not a single process but a series of loosely-linked processes which leave passengers relatively free to decide how they would move from check-in to boarding;

- While airlines recommend check-in times based on scheduled departure times, within limits, passengers are free to begin the journey through the departure process at a time they decide;
- Transfer passengers who make a significant proportion of Abu Dhabi Airport traffic face an indeterminate wait, possibly prolonged, before moving to departure;
- While the fixed physical layout governs passenger movement through emigration and security processes, passengers still retain some freedom of movement on deciding when they move from land side to air side or how and where they move around the terminal once on airside.;
- Only in the final stages of the process when actual time of departure is known does the final process exert 'pull' on passenger movement. It is in the airport's interest to maintain this freedom in order to maximise income from concessionary sales and commercial activities. This has the effect of making the process quite different from 'classical' Lean environments, whether in manufacturing or services;
- For reasons described in earlier chapters (Sections 1.5.2, 2.6, 3.3.1), the environment of any airport is now more subject to external influences than is the case in previously cited Lean studies. The threat of terrorism and organized criminal activity has been a large contributing factor. This gives the airport departure process the characteristics more of a system than a simple end-to-end process even at the level of individual processing stations (section 2.6) (Checkland 1981, Jackson 2003, Wu 1994) . Most of these can be significantly affected by external events at short notice and national and international regulations affect the content and operation of each process to a considerably extent than would be the case in either manufacturing or almost all service operations modelled previously;
- People are not 'components' (section 6.2.1). The demand for high levels of service quality is a significant factor in the minds of many passengers and most are intolerant to having movement closely regulated especially given the freedom of movement deliberately designed into airport concessionary space before and between processing stations;

- People behave far less predictably than components, especially in an airport environment which may be relatively unfamiliar to many passengers. In other Lean studies in different environments like hospitals and healthcare (Al-Nabit 2012, Burgess and Radnor 2013, T.P. and Mcclean 2010), people are more closely controlled between processes. This researcher observed the different behaviours of passengers when called from the Disney queue to the time when processing may begin as people collect together their luggage, travel a variable distance from the main queue to the processing station and extricate documents from pockets and bags ready for processing. This directly and significantly affects the capacity of each processing station because there is a necessary but unpredictable delay between the end of processing one passenger and the beginning of processing the next. This effect is present in all processing stations, and it varies not only between processing stations, but between different types of passenger and different group sizes;
- Central to classic Lean theory is the principle of ‘seven wastes’ (Section 2.5) (Ohno 1988). Table 2-2 of Section 2.5 shows that there is some difficulty in applying the seven wastes in an airport environment. Furthermore, as Table 2-2 of Section 2.5 shows subsequent researchers have developed at least another three additional wastes where once again, there is some difficulty in applying each fully. Nevertheless, difficulties with some ‘wastes’ are not insurmountable as this Chapter will shortly describe;
- Seasonality is not unknown in other operating environments. Nevertheless, airport environment are special because the departure and arrival processes are exposed to several cyclical factors, often simultaneously, which significantly affect airport operations (Section 6.2.1) which describes annual, seasonal, monthly, weekly and daily cycles whose effect may be cumulative;
- Rapidly expanding businesses may been evaluated under Lean principles previously even though they are relatively rare except in the case of business start-ups (Blank 2013). In manufacturing production-line and most service situations, growth are either slow or operations take place in the steady-state environment. In the case of Abu Dhabi Airport, expansion is a rapid and this

rapid growth looks likely to continue (Murel and O'connell 2011). Considering Lean improvements in these circumstances is fraught with difficulty;

- The design of airport terminals potentially makes providing additional resources and process station difficult and expensive, especially as there is a need to provide a clear and coherent flow to passengers who may be extremely unfamiliar with a particular terminal.

Nevertheless, despite these considerable difficulties Lean principles may still be applied in an airport environment as Table 2-1 (Section 2.4.1) which describes Lean fundamental concepts, shows. When one evaluates Table 2-2 (Section 2.5.1) this offers the greatest potential for improvement, together with the concept of using physical and human resources more effectively, though in a different way from that previously described in the literature.

8.3.2 Airport Simulation Barriers

The research showed that ebbs and flows of departing passengers are complex and changeable and subject to cumulative change as peaks in demand change daily, weekly, monthly and seasonally throughout the year. Adding to the problem, Abu Dhabi Airport is currently undergoing a period of significant expansion, especially in Terminal 3 as Etihad expands worldwide services. To evaluate the changes in full it would have been necessary to simulate airport services over at least two years to take account of expansion. This was impractical, from both the resource and analysis perspectives. Consequently, a different approach was taken. Simulation used the worst-case for the data collected during a single three-month period. Instead of attempting to develop a single set of rules which would need expert involvement, a more practical method of flow control is envisaged which could be administered by airport personnel ‘on the ground’.

8.4 Results After Rules Application

8.4.1 Check-in Process-Group

Table 8-1 Economy Check-in Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	03:55	12:04	mm:ss
	Imp	02:00	09:47	mm:ss
	% Imp	40.21 %	18.96%	
Median	Ob	04:14	10:14	mm:ss
	Imp	01:26	08:08	mm:ss
	% Imp	65.95%	20.58%	
Max	Ob	05:04	36:55	mm:ss
	Imp	03:42	15:20	mm:ss
	%Imp	26.96%	58.49%	
Min	Ob	02:18	01:25	mm:ss
	Imp	00:58	06:11	mm:ss
	% Imp	57.74%	-336.42%	
Std. Dev.	**Imp**	01:08.754	02:49.437	mm:ss

The resources of the entire check-in process in all classes are considered as a group. While numerically the demand in Economy-Class is the greatest and thus constitutes the largest problem at cumulative peak times, the need for higher service quality is greater in business and First-Class. This was not considered when developing the rules for the check-in group. Technical constraints imposed by the simulation system meant that the percentage of processing capacity of each processing station was not accounted for and consequently the final outcome overestimates the degree of improvement possible.

In the case of the check-in group of processes, excess processing capacity was observed in First and Business-Class and self-check-in was underutilised even at peak times.

The rules (Table 7-1) *in the circumstances tested* set a limit of queuing-time of ten minutes at which time more experienced check-in operators replaced less experienced operators diverted to other duties helping and directing arriving passengers. Second, the rules visualised when a total of eight Active Stations were operation 50% of passengers were redirected and assisted at self-check-in. Third, the rules visualised a visible marker which marked when the Disney queue had sufficient capacity to accommodate fifty-five passengers. Passengers queuing beyond this triggered the next stage which diverted passengers to a Disney queue adjacent to Business-Class (BC Disney) as well as other steps being taken. Fourth, to prevent unnecessary congestion in the departure hall, the size of the Disney queue was limited to 150 passengers and newly arriving passengers held from entering the queue. To ensure maximum flexibility, attendant check-in operators, freed from operating processing stations by the arrival of more experienced operators are available to use discretion to direct arriving economies-class passengers from the holding area to quickest moving queue in front of various processing stations. In practice, these operators would also assist passengers to ensure they have the correct documents, did not have excessively overweight or abnormal baggage. Those who did were directed to appropriate processing stations to avoid arriving at the check-in processing station and then delaying other ‘check-in ready’ passengers as they were redirected. The use of less-skilled operators in this way lessened the effect of reject and rework as statistically significant factors while at the same time contributing to training and up-skilling operators. It was further envisaged that as assisting operators became more skilled they would actively change or create rules which would further assist the quicker processing of passengers arriving at the departure lounge. Thus the parameter is given in this paragraph are indicative and not definitive.

Indicative results for standard Economy check-in passengers are shown in Table 8-1. Results for self-check-in passengers (Table 8-2) include those redirected from the primary Disney queue. Result for baggage drop passengers (Table 8-3), include those redirected from other queues. Tables 8-1 and 8-2 demonstrate notable (indicative) improvements over the current system.

Table 8-2 Economy Self Check-in Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	N/a	02:33	mm:ss
	Imp	0	0	mm:ss
	% Imp	0.00 %	100.00%	
Median	Ob	N/a	02:25	mm:ss
	Imp	0	0	mm:ss
	% Imp	0.00%	100.00%	
Max	Ob	N/a	08:40	mm:ss
	Imp	0	0	mm:ss
	%Imp	0.00%	100.00%	
Min	Ob	N/a	00:11	mm:ss
	Imp	0	0	mm:ss
	% Imp	0.00%	100.00%	
Std. Dev.	**Imp**	00:00.000	00:00.000	mm:ss

The rules for self-check-in passengers (Table 7-2) envisage two trigger points. The first is when passenger waiting-time exceeds 10 minutes. This triggers operator assistance to make check-in more effective. For some passengers, this involves reassignment to the baggage drop queue after completing optionally-assisted self-check-in. Secondly, a visual indicator trigger point in the Disney queue which limits the capacity of the queue to thirty persons before passenger begin to be partially redirected to the BC Disney queue.

Table 8-3 Economy BagDrop (Check-in) Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	02:39	05:34	mm:ss
	Imp	01:24	04:01	mm:ss
	% Imp	47.20%	27.82%	
Median	Ob	02:43	04:37	mm:ss
	Imp	01:27	04:16	mm:ss
	% Imp	46.66%	7.52%	
Max	Ob	03:19	13:20	mm:ss
	Imp	02:27	07:00	mm:ss
	%Imp	26.35%	47.50%	
Min	Ob	01:52	01:15	mm:ss
	Imp	00:24	00:50	mm:ss
	% Imp	78.17%	33.06%	
Std. Dev.	**Imp**	00:34.693	01:37.364	mm:ss

In the case of Economy Baggage Drop, the rules in Table 7-3 are limited in this case to rostering higher-skilled operatives and redirecting passengers when trigger points of time and queue length are reached. Previous operators replaced by highly-skilled operators are then freed to assist passengers in the BC Disney queue. In this case, the queue length is set at an abnormally low level in the rules to demonstrate the effects on business and First-Class check-ins process times.

Table 8-4 Business-Class Check-in Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	02:30	06:52	mm:ss
	Imp	01:22	04:38	mm:ss
	% Imp	45.41%	32.68%	
Median	Ob	02:38	06:12	mm:ss
	Imp	01:20	04:03	mm:ss
	% Imp	49.12%	34.60%	
Max	Ob	03:28	19:05	mm:ss
	Imp	01:50	08:53	mm:ss
	%Imp	47.25%	53.51%	
Min	Ob	01:06	01:47	mm:ss
	Imp	01:01	03:27	mm:ss
	% Imp	7.16%	-93.49%	
Std. Dev.	**Imp**	00:12.158	01:23.117	mm:ss

Business-class check-in operates using individual queues for check-in desk of a length which can accommodate ten passengers. In this case, the rules (Table 7-4) envisaged a shorter acceptable queuing-time than for Economy passengers and trigger points which were less than the queue length to allow time for highly-skilled operators to replace those of lesser skills. These queues are fed by directly arriving Business-Class passengers given priority over the BC Disney queue which contains overflow Economy passengers who are in turn directed by staff to the first available check-in desk with a queue length of less than ten person. As soon as full capacity is reached in the entire Business-Class section with all queues activated, spare capacity in First-Class is freed by reassigning two First-Class check-in desks to Business-Class passengers. This arrangement, whose results are shown in Table 8-4, still allowed service and check-in times for Business-Class passengers to be (indicatively) improved.

Table 8-5 First-Class Check-in Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	02:30	06:52	mm:ss
	Imp	02:51	06:09	mm:ss
	% Imp	-13.92%	10.44%	
Median	Ob	02:38	06:12	mm:ss
	Imp	03:28	07:17	mm:ss
	% Imp	-31.85%	-17.39%	
Max	Ob	03:28	19:05	mm:ss
	Imp	05:09	11:08	mm:ss
	%Imp	48.37%	41.66%	
Min	Ob	01:06	01:47	mm:ss
	Imp	00:02	00:03	mm:ss
	% Imp	97.60%	97.07%	
Std. Dev.	**Imp**	02:00.242	04:16.168	mm:ss

Table 8-5 demonstrate indicative results for First-Class passengers. While in percentage terms, results for mean (non-zero) processing queues appear to be worse, median waiting is (indicatively) worse than by less than one minute, and maximum waiting by just one minute and forty-one seconds. Management may judge in principle this relatively small degradation of waiting time compared with the much larger improvements for the overwhelming majority of passengers is acceptable. On the other hand, given the importance of First-Class passengers they may consider the rules for Business-Class passengers should be changed.

8.4.2 Emigration Process-Group

Table 8-6 Economy Emigration Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	00:34	04:10	mm:ss
	Imp	00:34	03:35	mm:ss
	% Imp	0.29%	13.91%	
Median	Ob	00:34	03:00	mm:ss
	Imp	00:35	03:26	mm:ss
	% Imp	-1.34%	-14.24%	
Max	Ob	00:45	21:17	mm:ss
	Imp	00:40	05:24	mm:ss
	%Imp	12.30%	74.62%	
Min	Ob	00:22	00:13	mm:ss
	Imp	00:27	02:42	mm:ss
	% Imp	-24.68%	-1144.74%	
Std. Dev.	**Imp**	00:03.728	00:43.183	mm:ss

The rules for emigration processing stations are in Tables 7-6 and Table 7-7. As with the check-in group of processes, the combined resources of all emigration stations are considered. Indicative results are shown in Tables 8-6 and 8-7. The experimental rules envisage replacing all emigration personnel with highly-skilled operatives when queuing-time equals or exceeds five minutes and queue length equals or exceeds eight passengers. The rules further reassign two processing stations from business and First-Class when the queue length reaches eighty, just 53% of its full capacity. While this has an indicative large effect on the maximum queuing-time, there is a worsening of the median queuing-time. On the other hand, the indicative mean (non-zero) queuing-time for First and Business-Class shows marked improvement despite the loss of two processing stations indicating that the replacement of personnel with those of higher skills is effective. Nevertheless, bearing in mind the fast-growing number of passengers going through the airport, the figures indicate a need for additional capacity or alternative measures for dealing with Economy Emigration performance other than that which can be provided by reassigning First and Business-Class processing stations.

Table 8-7 First and Business-Class Emigration Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
	Ob	01:33	02:55	mm:ss
Mean	**Imp**	00:32	03:37	mm:ss
	% Imp	65.50%	-24.00%	
	Ob	01:35	02:31	mm:ss
Median	**Imp**	00:23	02:04	mm:ss
	% Imp	76.16%	17.63%	
	Ob	02:45	08:51	mm:ss
Max	**Imp**	01:45	08:51	mm:ss
	%Imp	36.17%	-0.01%	
	Ob	00:17	00:22	mm:ss
Min	**Imp**	00:09	00:21	mm:ss
	% Imp	48.71%	4.02%	
Std. Dev.	**Imp**	00:26.997	03:07.566	mm:ss

8.4.3 Security Process-Group

Table 8-8 Economy Security Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
	Ob	00:33	04:25	mm:ss
Mean	**Imp**	00:16	01:53	mm:ss
	% Imp	51.94%	57.33%	
	Ob	00:25	03:51	mm:ss
Median	**Imp**	00:16	01:49	mm:ss
	% Imp	34.96%	52.74%	
	Ob	00:56	22:23	mm:ss
Max	**Imp**	00:21	03:20	mm:ss
	%Imp	62.62%	85.12%	
	Ob	00:18	00:14	mm:ss
Min	**Imp**	00:11	01:13	mm:ss
	% Imp	38.28%	-423.49%	
Std. Dev.	**Imp**	00:02.913	00:29.486	mm:ss

In the case of the Security Process-Group only Economy, First and Business-Class resources may be grouped together because of the physical layout of the airport that is, resources of stations serving transfer passengers of all classes are excluded from group resources.

The experimental rules in Table 7-8, and Table 7-9, envisage replacing operatives with highly-skilled staff when any Class's queuing-time exceeds five minutes and in the case of Economy-Class, the queue length equals or exceeds twenty, which is significantly less than the available queue length of 100. Using visual trigger points at the Disney queue, one processing station may be assigned jointly to all classes. This steadies the flow-at maximum queuing times at the minimum level but results on major (indicative) improvements to the maximum (Table 8-8). The indicative effect of these improvements on business and First-Class passengers (Table 8-9) is also marked.

Table 8-9 First and Business-Class Security Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
	Ob	01:22	02:49	mm:ss
Mean	**Imp**	00:22	01:32	mm:ss
	% Imp	73.69%	45.36%	
	Ob	01:17	02:39	mm:ss
Median	**Imp**	00:21	01:26	mm:ss
	% Imp	72.83%	46.04%	
	Ob	02:18	07:34	mm:ss
Max	**Imp**	00:31	02:31	mm:ss
	%Imp	77.30%	66.73%	
	Ob	00:44	00:40	mm:ss
Min	**Imp**	00:15	00:58	mm:ss
	% Imp	65.40%	-42.92%	
Std. Dev.	**Imp**	00:04.569	00:19.470	mm:ss

Security processing for transfer passengers who now form a large proportion of total departing passengers are isolated from other security stations because of the physical layout. This limits the ability to combine existing resources. Consequently, the rules in Table 7-10 were developed independently from the main security group. In effect, the only practical option is to improve operative skill using replacement operatives. Triggers for replacement are queuing times and queue lengths with visual triggers in the Disney queue. In Table 7-10 trigger points are locations significantly before the end of the physical queue length. The simulation results (Table 8-10) demonstrates a marked (indicative) improvement on performance although the results for the minimum level of maximum queuing-time are worse by some forty-seven seconds.

Table 8-10 Transfer Passenger (All-Class) Security Performance: Results after Simulation Results Applied

		Mean (Non-zero) Queuing-time	Maximum Queuing time	
Mean	Ob	03:28	08:48	mm:ss
	Imp	00:17	02:33	mm:ss
	% Imp	92.01%	70.92%	
Median	Ob	04:06	07:36	mm:ss
	Imp	00:15	02:52	mm:ss
	% Imp	93.90%	62.39%	
Max	Ob	04:15	20:00	mm:ss
	Imp	00:26	03:42	mm:ss
	%Imp	89.93%	81.51%	
Min	Ob	02:04	00:47	mm:ss
	Imp	00:11	01:34	mm:ss
	% Imp	91.09%	-100.84%	
Std. Dev.	**Imp**	00:04.301	00:39.355	mm:ss

8.5 Lean Implementation in Passenger Departure Flow

When first evaluated, using classic Lean measures, especially the '7+3 wastes' is difficult. Effects of strong external influences and the dissimilarity between passenger departure flow in a major international airport and those environments previously evaluated as suitable Lean improvement appears to be an almost insurmountable barrier when measured against classic Lean theory. Nevertheless, these experimental results show even such limited application of Lean principles can still improve performance in every group of process station.

The overall aim is to develop a system of improvement which could be managed by line managers and suitably experienced operatives without the need for complex mathematical systems, though they have been used in this research to prove that Lean improvement is not only possible but can lead to major performance gains (Tennant, et al. 2002).

8.5.1 Developing a Sustainable Model for Continuous Improvement

A key element of Lean is that not only does improvement take place immediately but continuous improvement occurs. This means using a holistic approach which focuses on key issues to achieve this (Lim, et al. 1999, Womack, et al. 1990).

To be most effective, any model which involves continuous improvement must include the means to rapidly resolve difficulties using problem-solving methods described earlier (Section 3.7.1-2). Enhancing managerial and operator involvement become key elements in making improvements (Tennant, et al. 2002) to the passenger departure process in Abu Dhabi Airport. This research involves identifying problem areas in each element of the departure process rather than setting hard and fast rules and attempting to provide 'definitive solutions' from simulation. In reality, universal rules do not exist in this sense they were described in the previous Chapter. Only by applying a bottom-up approach to solving problems within the departure process will staff become involved in constantly looking to see how they can improve the entire process-group. This will mean setting up problem-solving teams dedicated to improving systems in specific areas of the departure process. This falls well within the split-management system where responsibility moves from one managing organization to another with every group of processes. Thus airline teams may be responsible for improvements in check-in and boarding, border control teams will address problems in emigration and security authority teams will address problems in the security process-group while the Airport Authority plays a co-ordinating role.

Problem-solving frameworks developed by Harley (1995) and Cervone (2006) were described earlier in this work in Section 3.7.2. Building on these works

1. Form process-group-focussed problem-solving teams;
2. Identify the principles involved, based on this research work;
3. Agree the methodology for problem analysis;
4. Define a specific problem objectively;
5. Assemble the facts for various levels of demand or conditions;
6. Quantify goals and outcomes, including the flow of information around the group;
7. Analyse the potential effect on different parts of the process-group;
8. Identify criteria for solutions;
9. Propose and agree simple key intervention milestones and trigger points;
10. Implement solutions;
11. Measure outcomes;
12. Verify outcomes were as anticipated;
13. Modify solutions, if necessary;
14. Return to step 3 or 4 as appropriate and repeat.

In the short-term, as part of step 2, after making clear there are no universal answers to resource allocations, continuous improvement teams should be directed to:

1. Develop the ability to use active and inactive processing capacity more effectively and thereby reduce waste by:
   a. Identifying where excess or inactive process-group capacity exists under varying conditions of cyclical demand, especially at peak periods throughout the year;
   b. Developing and record simple local rules based on key queue lengths and mean processing times;
   c. Establishing simple visual markers which identify when:

    i. to begin diverting passengers to other queues within the same process-group in ways described in Section 7.3.
    ii. to open inactive stations or close excess Active Stations.

2. To decrease cycle time at processing stations by utilising different experience levels at different times of demand by
    a. Identifying at which stage to deploy differently-skilled team members using simple rules involving:
        i. average passenger waiting-time and
        ii. key queue lengths with simple visual markers
    b. Improving the roster system in a way that shortens changeover times between differently-skilled team members;
    c. Deploying replaced processing station operators to interact with passengers either to:
        i. re-direct passengers to alternative processing resources; or
        ii. to intervene with passengers to remove waste through rejects and rework. For example staff will help passengers in the check-in queue to pre-identify overweight baggage using portable weighing equipment or baggage which needs special processing while waiting rather than at a processing station;
        iii. to aid passenger prepare for processing while waiting. For example, staff will pre-check documents in the waiting queue to ensure they are readily available and in order for when the passenger is called to the processing station;
    d. Developing a team-based peer-group training system in addition to any management-provided training. This will ensure less experienced operatives gain the necessary skills to carry out the tasks in 2(b) and (c) above, using role playing, discussion groups and peer mentoring (Piskurich, *et al.* 2000).

When the continuous improvement is well-established, statistically significant variables listed will be presented to continuous improvement teams in accordance with the findings in Sections 6.4.1.1-5, 6.4.2.1-2, 6.4.3.1-3 for additional medium and long term-improvement.

To be most effective the organization, including the Airport Authority, airlines, border control agencies, and national security and their respective senior and line managers must be committed to continuous improvement (Womack and Jones 1996, Womack, et al. 1990). They will be responsible for putting in place the enabling mechanisms of training in teamwork as well as encouraging and monitoring continuous improvement programmes. For their part, individual employees must be helped to develop awareness and understanding of the aims and objectives of Lean improvement. In this way, people in each process-group and across process groups must be encouraged to engage proactively in continuous incremental improvement so that people will learn from their own and others' experience what are the most and least effective methods of improvement.

8.6 Achieving Synchronous Flow by Reducing the Effect of Variability

The lean philosophy was originally developed to counter the effect of variability in a flow line in mass production. Initially during this research, it was somehow natural to view the passenger departure process in the same terms. However, research indicated that in most circumstances, and certainly in the case of Terminal 3, a mass production flow line is a false analogy. Nevertheless, this is how to some extent airport services are arranged by passenger class, though with large intermediate concessionary areas for economic reasons and to account for uncertainties of departure times. This leads to overprovision of resources in some areas and under provision and others. Ad hoc rules mean that queuing capacity may bear limited relation to efficient flow of passengers. This called for entirely different thinking although still within the Lean philosophy.

If one continues the manufacturing analogy, this involved viewing groups of similar processing stations which were separated by passenger class as a manufacturing cell rather than part of an end to end flow line (Slack et al, 2010). Such cells deliver into intermediate or concessionary areas rather than being part of a strictly end-to-end line.

By thinking of a cellular process of related operations, one may still apply lean, especially when it comes to reducing the effective demand variability and different types and classes of passenger, one may achieve higher productivity in each resource and greater responsiveness to various changing flow conditions.

8.7 Quick Response to Variability

The essence of the new flow-control and improvement methodology developed during this research is that it does not need specialist expert intervention but may be implemented by airport managers and employees, whichever entity employs them. After relatively simple training, this will permits an immediate, in-situ response to changing demand conditions however they may vary.

8.8 Ability to Predict and Plan Ahead

Applying this methodology (later referred to as SERVICE - section 8.12) will allow airports to not only immediately manage passenger flow and maximise the use of resources to apply them where needed, but will also allow a strategic view to be taken of all operations and processes. When difficulty occurs in applying the process to improve flow, it will allow the airport authority to accurately predict areas where they must provide additional resources. Essentially, the SERVICE methodology is tactical and strategic at the same time placing control in the hands of line managers and staff, but allowing senior managers and the Abu Dhabi airport Authority to still decide levels of service to individual types and classes of passenger.

In addition, by developing a simulation model specific to the airport which may be updated from time to time, the methodology will provide an additional ability to conduct a what if analysis of the type not possible in the real life environment without interrupting actual operations. As well as the immediate effect from the application of the SERVICE methodology on a daily basis, the addition of a simulated model will also provide a way to convince management about the necessary changes to improve the process from both data analysis and visualisation aspect.

8.9 Adoption of Proposed Methodology in Other Industrial and Service Sectors

This methodology may be applied in other airports and in airport types unlike this major international hub. From this perspective, Abu Dhabi International Airport has provided an extreme example because of its strategic objectives, exceptionally fast growth and the nature of its operations, though it is not entirely unique in this respect, even though major international hubs tend to have a more restrained growth rate. This makes application of the methodology to other airports even more certain to produce good results for the passenger departure process.

Airports exist in a special environment, unlike any other because of national and international regulation, pressures to combat organised crime and terrorism, wide and usually cumulative fluctuations in demand daily, weekly monthly and seasonally, and because of the uncertainty of arrival and departure times which surround every airport. Nevertheless, they share characteristics with other operations which also experience wide fluctuations in demand and similar problems about regulation and so on. The SERVICE methodology could be applied to many other undertakings which fall into these categories. The most obvious are transport terminals of various types and entertainment complexes such as theme parks. Various parts of the holiday industry would also benefit from this approach. From that perspective, this research and its findings are highly significant.

8.10 Experience and Results of the Research

The special environment of any airport, especially a major international hub made applying Lean principles difficult. This resulted from the large presence of Class I *muda* which could potentially change, perhaps dramatically, at short notice. This made this research significantly different from previous applications of Lean philosophy. Also, large, cumulative variations in demand set in an environment where rapid expansion of the airport is taking place also created major difficulties because of the shifting flow of passengers. This meant that without carrying out field research for prolonged periods even the most accurate recording was only able to provide a short-term snapshot of demand at any given time. This involved changing the approach during the research to account for significantly shifting demand and external factors. This researcher recognised in such circumstances, no universal formulas would produce a practical method useful for effectively managing flow.

Thus, this researcher did not treat individual processing stations, all of which heavily involved Type I *muda* to detailed Lean analysis. Instead he modelled them in detail and then subjected the resultant processing station to a ‘black-box approach’ and only evaluated inputs and outputs. This facilitated a focus on passenger flow within the buffer areas. The output of simulation, Taguchi and ANOVA analyses are detailed in

Chapter 6. The model, simulated over an entire single day used peak annual flow and thus became a ‘worst case’ for the sampling year. This researcher recognised this not only was a snapshot of flow, but one already overtaken by increases in overall passenger flow due to airport expansion.

The output and analyses were compared with the five key principles of Lean listed in Table 2-2. Several touch on matters which are strategic rather than operational issues. The most important of these is the difference between traveller classes. To take a simplistic view the treats all customers as equal ‘components’ in the system would be wrong. Business-class and especially First-Class travellers expect service standards noticeably better than Economy-Class travellers. Thus, one cannot apply identical process parameters. The service level they receive and the delays they experience when queuing ahead of processing stations is a matter of significant concern for the Airport Authority and airlines. Any method of flow improvement proposed must address and leave decisions about queuing times to local management. This researcher carefully considered these problems when framing Lean solutions. Also, in Terminal 3 there are places where the flow of different classes combines, adding to difficulty.

When this researcher analysed quantitative output of the first simulation, he evaluated the statistical significance of certain factors. This had the aim of producing a simple means of improving passenger flow and reducing queuing-time ahead of processing stations. Evaluation identified unused or underused resources, especially in check-in as a major waste. Process time at various stations was also statistically significant but because of Class I *muda* could not be dealt with directly. The waste ‘Untapped human potential’ (Abdi et al, 2006) was the key to this problem. While operative skill levels were not normally statistically significant, they provided the most practicable way to both improve process time and continuously improve operative skills.

8.11 Recommendations

8.11.1 SERVICE Principles

This research has now developed various rules from parameters based on the acronym SERVICE. This will help airline managers and staff to eliminate the waste of available resources and so increase passenger flow through various stages of the process in line with Lean philosophy. In developing these parameters, this researcher had several important principles in mind as well as the ‘five key principles of Lean’ (Emiliani 1998).

SERVICE represents:

STRATEGIC: While Lean improvements are mainly operational in principle, they must also accommodate marketing, economic and other strategies of the Airport and its operating partners without conflict. Lean improvement must also strategically account for internal and external factors which directly affect individual processes within the entire passenger departure process. Only then will operating partners fully accept and apply periodic Lean adjustments to processes;

ELIMINATING WASTE: Research and analysis in Terminal 3 showed that many processing stations resources were unused or underused at key periods when the Airport kept passenger classes and processes discrete and separate. The new rules help periodically divert passengers to such resources. This enables utilisation of all available capacity of the airport when needed, though without interrupting service quality. The research identified the second key waste as ‘untapped human potential’ (Abdi, et al. 2006) as a way of better using an avoidable waste. Better-skilled operators could potentially improve service times within operating stations without otherwise affecting their normal processes. Less-skilled operators are then freed to aid or re-direct passengers and optimise available information ahead of passengers presenting themselves at processing stations.

REPRODUCIBLE: The simple principles involved allow managers and moderately-trained staff to optimise queue lengths and queuing times every time no matter what the circumstances. As optimisation becomes more difficult, application of these rules will enable managers to identify and report areas of developing problems where the Airport must structurally develop increased resources;

VISIBLE: Visibility is at the heart of the simplicity of this series of Lean improvements. The rules merely need operating staff to place simple visible markers or flags alongside either Disney or individual queues to show when passenger exceed a predetermined queue length. This will rarely be when the physical size limits of the queue or unacceptable waiting times are reached. Tables 7-1 to 7-11 give e*xamples* of these rules subject to periodic adjustment based on experience. Indeed, as the indicative results in Tables 8-1 to 8-10 deliberately show, without care, mean and maximum queuing-time may become worse needing immediate adjustment. 'Periodic' in this case means considering daily, weekly, monthly, seasonal and annual variations in numbers of passengers passing through process station at any given time.

IMPROVABLE: Developing a sustainable model for continuous improvement is a key principle of Lean (Section 8.4.1). The rules are designed to promote this in several ways.

1. Instead of removing less-skilled operators from rosters when higher-skilled staff replaces them in processing stations under the rules, lower-skilled staff become a key resource in the improvement process. They achieve this by redirecting passengers to underused resources in a planned way, assisting them to prepare better for entry into the actual processing station or monitoring improvements. Continuous improvement occurs when lower-skilled staff gain customer service skills, or by directly experiencing effects of improvements;
2. Experiential learning is fed back after seeing the effects of changes to help better future decision-making on where to place queue markers or to set time limits;
3. Operating managers and staff recognise the improvement process is always adjustable and allows them to flexibly set limits whatever the circumstances they face. This encourages ownership of process improvement;

CUSTOMER FOCUSSED: Research by various authors including Jin-Woo, *et al.* (2006) and Mei Ling, *et al.* (2010) has shown just how important service quality is to individual passengers when making their choice of which airports and airlines to use. For reasons described in Section 1.3 and 1.5.6 Abu Dhabi Airport places a high value and service quality and service quality is integral feature of the Lean philosophy. Operating rules must therefore recognise passengers are people and not components. Also, all parties to the departure process must have the freedom to develop service to different classes of passengers to different levels within the rules;

EASY TO APPLY: Complex rules which need specialists to apply are incapable of making the rapid adjustments necessary to ensure continuous 'leaning' of the process. Instead, using the principals of these rules, simple numerical parameters based on experience allow staff or managers to amend actual numbers to suit changing circumstances.

8.11.2 Applying Lean Improvements

To apply process improvement rules, moderately-trained line managers or personnel use the following methodology during periods of rising demand:

1. Use a 'Plan, Do, Check, Act' process at the start of each shift.
    a. Plan: Determine policy and decide in advance what acceptable queuing times are for different passenger classes. Similarly, considering likely demand for the day and time of day decide where target markers should be placed to measure the average number of passengers in any queue (at first) under the rules given in Tables 7-1 to 7-11. Remember to plan for any unexpected changes in the external environment which may occur;
    b. Do: Involve operating personnel and communicate the process so everyone on shift is clear what is expected of them. Provide the right equipment to enable changes to queues to be measured or made or suitable signage. Introduce steps 2 to 7 below;
    c. Check: Measure and record the effects of changes aiming to improving performance progressively in various demand conditions. Assess performance of management and operating staff aiming to provide further training and instruction of individuals if necessary;
    d. Act: Review performance and take action on lessons learnt, including across work shifts.
2. Introduce the 'Do' phase by progressively increasing capacity by opening processing stations following (at first) the example conditions shown in Tables 7-1 to 7-11;
3. Examine the entire process-group and identify underused or underused resources. 'The entire process-group' means all classes of: check-in,

emigration, security and boarding. Prepare if necessary to divert passengers to these resources;

4. Set up target markers alongside to queues appropriate to the demand for the day and time;
5. Introduce the ‘Check’ phase
6. Measure queuing-time using AQT measurement rules;
7. Use target markers and queuing times to carry out improvement processes (at first) under the rules in Tables 7-1 to 7-11. Re-direct passengers to other parts of the process-group, roster highly-skilled staff to work in processing stations; reallocate lower-skilled staff and so on, until optimum conditions are met at peak times;
8. Introduce the ‘Act’ phase.

During times of falling demand, managers and operating staff progressively reverse the process while ensuring operational parameters are still met.

8.12 Limitations of the Research

Field research was limited by the need to observe SMART criteria (Section 6.4.4) and remain constrained in time and scope. To capture the full extent of cyclical effects on passenger flow it would have been necessary to collect much more comprehensive and detailed field data from more than twelve months in entire 24-hour periods. This simply was not feasible. Accordingly, the research and more specifically the simulation was necessarily a snapshot of just some of the conditions occurring in Departure Passenger Flow. This created the impossibility of developing a universal Lean solution that would fit every demand conditions without developing a much more complex, specialised and dedicated simulation system. Thus output from generalised simulation in this airport can never be more than illustrative and the output tables in Section 7.3 should be read accordingly, and should not be read as definitive. Equally, neither should the simulation rules listed in Tables 7-1 to 7-11 in Chapter 7 and the underlying data contained in Appendixes be taken as definitive and universal. While they might not be definitive, this in no way reduces their value as illustrative examples. Nor does it prevent them being confirmative that Lean principles can be successfully applied in passenger departure process in a major airport such as Abu Dhabi Airport.

The next and final Chapter of this thesis will present the conclusions of this research and its contribution to knowledge in the field. It will also make recommendations as to further research which may be undertaken in this field.

Chapter 9 : Conclusions and Suggestions for Future Work

9.1 Introduction

This Chapter presents conclusions of this research and its relevance to research aim and objectives laid out in Section 1.4. The Chapter also states briefly the contribution to knowledge which this research has achieved. The final part of this Chapter recommends further work which could flow from this research project.

9.2 Conclusions

The main conclusions of this research can be summarised in the following:

1. Abu Dhabi Airport employs a revenue model vital for its financial well-being which incorporates concessionary activity. It uses these as extended buffers between related groups of processing. Most flights have delayed departures because of local or external factors and the intermediate, concessionary buffers create the means of absorbing passenger attention over uncertain intervening periods between check-in and actual departure. Unusually for Lean applications it is arguably in any airport's interests to lengthen the process to the extent passengers will reasonably bear rather than lessening total time spent in the airport departure process. Time spent becomes subjective economic and strategic decision rather than an objectives measure normal in Lean.

2. Lean philosophy has its own special definitions of waste known as the 'Seven Classic Lean Wastes' or *muda*. This research described them in detail and their application to airport processes. It became clear most wastes in processing stations fell under the definition of Type I *muda*. Each Type I *muda* were excluded given those difficulties concerning the special environment which surrounds airport operations. These are not present in other operations in most manufacturing or service environments. This exclusion left the research free to concentrate on value-added activities and avoidable Type II *muda*.

   As well as the Seven Classic Lean Wastes, various authors later identified three more Lean wastes. The high proportion of Type I *muda* creates an unparalleled form of process under which to consider applying Lean compared with previously considered cases in manufacturing and service literature.

3. This research used simulation principles to develop a more complex model than those in previous research and more realistically modelled Abu Dhabi Airport. Then this researcher used the simulation program's quantitative output to support Lean conclusions using various parameters to closely match reality. Simulation used this way directly models the behaviour of processes and examines complex random variables whose precise distributions are not easy to evaluate mathematically.

4. Simulation provided an experimental approach to studying changing parameters developed through the application of Lean. This helped develop rules useful to relatively non-technical staffs which enable them to react to constantly changing circumstances and variations in passenger flow. The entire process is subject to wide daily, weekly, monthly, seasonal and annual fluctuations, most of which are cumulative. In this, the airport environment was again seen to be different to most environments where Lean has been previously applied. This researcher then subjected quantitative output from the simulation model to the Taguchi Method allowing further analysis to isolate and identify the most important parameters for improvement.

5. The statistically-based Taguchi Method first developed to integrate analytical methods into engineering processes to achieve greater stability and capability. It is important means of underscoring responsiveness towards customer satisfaction. The Taguchi Method underlines the importance of lessening process variability around a specific target value. This involves carefully selecting design parameters (factors) able to withstand variations from the external environment. In this case, this researcher analysed signal, control and noise factors and visually portrayed signal-to-noise ratios. He used these to decide the ideal control factors with which to increase robustness and improve performance. This researcher then used analysis of variance (ANOVA) techniques to further analyse experimental observations and isolate the most important factors.

9.3 Contribution to Knowledge

This research has shown that large differences exist between the operating environment of a major international airport and those of processes to which Lean principles have previously been applied. Nevertheless, despite these differences, this research has proved the Lean philosophy may be usefully applied to airport operations.

1. Addressing the Issues due to type 1 waste; Notably, those people previously researching airport departure processes have largely ignored many of the environmental factors, fundamental to modern airport operations which contribute directly to Type I waste in the departure process. This research identified many areas where unavoidable Type I *muda* occurs. Arguably they may have inhibited applying Lean thinking to airports departure processes in the past. It analysed when correct to do so, how obstacles to process improvement may be overcome by applying other *muda* elimination techniques.
2. Systematic examination of passenger departure process: The contribution of this research arises from its systematic examination of the passenger departure process. The research has facilitated developing a detailed model which addresses both particular process groups and the effects of passenger class on the allocation and use of resources. Operating conditions within the passenger departure process mean that understanding the special operating environment of airports is vital. The research identified that system theory can give an important perspective. Lean philosophy and systems theory combined will help researchers understand better the implications of internal and external factors which impact all parts of the departure process. It will also aid other research where environmental factors have a major impact on internal processes.
3. Improved Modelling Approach: The research resulted in a simulation model of the airport much more accurate and detailed than those described in previous studies of passenger departure processes. The research then proved an improved model such as this may be used experimentally to support conclusions reached from the broader application of Lean philosophy. In this case, this researcher combined simulation results with statistical analysis. To achieve this researcher used Taguchi methods and ANOVA to clearly identify the most important areas in which Lean improvements could take place. This was despite the large-scale presence of Type I *muda* and the wide dissimilarities with other processes to which Lean was previously applied.

4. Optimal Resource Allocation: Previous efforts at improvement in Abu Dhabi Airport have been somewhat ad hoc and aimed at providing sufficient resources for each class and importantly sufficient queuing space to accommodate an inefficient process. This research has found and confirmed by simulation that by treating similar processing stations of whichever type and class as part of a group or cell and considering available resources in entirety, optimal resource allocation can be achieved in varying circumstances and no matter what level of passenger flow occurs.
5. Wider Applicability: By carrying out research in a major international hub airport, this research can be used to equally improve other similar or smaller airports. The research methods used and methodology can similarly be applied to other facilities especially those which have problems of regular, significant fluctuations in demand and those which suffer a high impact from special internal or external environmental factors.
6. Recognises Importance of Process as a System: Previous researchers who have addressed the entire departure process have treated the process as if it were a flow-line in a manufacturing process ignoring internal and external environmental factors. While the main focus was on Lean improvements, this research recognised the importance of the environment and briefly used a system view to better understand the environmental impacts on the passenger departure process.

9.4 Significance and Findings

This researcher observed and analysed the effects of substantial and cumulative peaks and troughs in demand against a background of rapid development of Abu Dhabi Airport. This researcher also evaluated the special internal and external effects on the processes, often at short notice. Consequently, this researcher recognised there is no single ‘universal’ solution because of the major need for operational flexibility and for a close correlation between operational and strategic need. Despite these many difficulties the results of this research are a practical and straightforward series of improvements which may be applied by airport staff themselves without need for complex computer models, simulation or dedicated experts. This will create conditions for continuously improving process performance during the passenger departure process. It will also help managers accurately identify critical areas where more radical action of increasing physical resources are needed.

This research has significant implications for other researchers, airport management organisations including operating partners and designers of airport facilities. Furthermore, having recognised the importance and large multi-periodic fluctuation in the flow of people and the significance of the impact of the internal and external environment and the limitations of fixed installations where adding resources may call for major changes, the findings of this research are potential of significance to those undertakings with similar characteristics and designers of installations, systems and processes needed for them.

9.5 Recommendations for Further Work

This research can simplify major practical improvements to the passenger departure process. Because of limits in the scope and time of this research, the study could not address the entire process including all the sub-processes or operating stations not field test the combined SERVICE and Application methodology. The findings and recommendations will help later improvement studies. The findings of this research will further enable other researchers to develop improved sub-processes considering those internal and external factors in the environment which affect them substantially more than previous research has shown.

Given the time and resource restrictions imposed by any Doctoral research, it was only possible to validate the methodology based on a small snapshot of operations over a short period. Ideally researchers should simulate and evaluate operations over a much longer period using a much expanded data set. Only then can the illustrative rules developed by this project be further extended to give a much more definitive and exact guide to operating parameters. This will enable later researchers to create a full set of rules more widely applicable to all airports.

Viewing an airport as being operationally parallel to a manufacturing process or to those service operations to which Lean has more commonly been applied is misleading. This results from the special nature of airport operations and constant external and internal influences on them. The brief examination of Hard and Soft Systems

Methodology in Section 2.6 showed its potential value for evaluating, analysing and improving the passenger departure process as an alternative or in combination the methods used in this research.

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General Appendix

Appendix A 1

Do-file for CIE.dta

***Prepare Data for ANOVA

```
use "D:\WORK\THESIS\DATA for THESIS\ANOVA\CIE.dta", clear

gen c_time = cyc_time

recode c_time (1.5666=1) (1.9333=2) (2.7666=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.0013=1) (0.0038=2) (0.0063=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0003=2) (0.0004=3)

label variable r_ject "% Reject made categorical"

gen b_status  = bag_status

recode b_status  (0.02=1) (0.08=2) (0.9=3)

label variable b_status  "Baggage Status made categorical"

gen c_gs8  = gs8

recode c_gs8  (0.02=1) (0.08=2) (0.1=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.7=1) (0.75=2) (0.88=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"

gen c_gs1  = gs1

recode c_gs1  (0.1=1) (0.17=2) (0.2=3)

label variable c_gs1  "Passenger Group Size 1 made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8
c_gs3 c_gs1
```

```
***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Working

*Active Station, Cycle Time

anova working active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** WIP

anova wip active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3 c_gs1
```

Appendix A 2

Do-file for CIEDB.dta

```
***Prepare Data for ANOVA

use "D:\WORK\DATA for THESIS\ANOVA\CIEDB.dta", clear

gen c_time = cyc_time

recode c_time (0.9=1) (1.65=2) (2.4833=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.0017=1) (0.005=2) (0.0083=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0002=1) (0.0003=2) (0.0005=3)

label variable r_ject "% Reject made categorical"

gen c_gs8  = gs8

recode c_gs8  (0.02=1) (0.08=2) (0.1=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.7=1) (0.75=2) (0.88=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"

gen c_gs1  = gs1

recode c_gs1  (0.1=1) (0.17=2) (0.2=3)
```

```
label variable c_gs1  "Passenger Group Size 1 made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1

***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1

*** %Working

anova working active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1

*** WIP

anova wip active_sta c_time r_work r_ject op_exper daily_dmnd c_gs8 c_gs3 c_gs1
```

Appendix A 3

Do-file for CIES.dta

```
***Prepare Data for ANOVA

use "D:\WORK\DATA for THESIS\ANOVA\CIES.dta", clear

gen c_time = cyc_time

recode c_time (0.65=1) (1.4833=2) (2.3166=3)

label variable c_time "Cycle Time made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2) (0.0003=3)

label variable r_ject "% Reject made categorical"


*** Throughput

anova thro_put active_sta c_time r_ject daily_dmnd

*** %Working

anova working active_sta c_time r_ject daily_dmnd

*** %Waiting

anova waiting active_sta c_time r_ject daily_dmnd
```

Appendix A 4

Do-file for CIBC.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\CIBC.dta", clear

gen c_time = cyc_time

recode c_time (1.5666=1) (1.9333=2) (2.76667=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.0013=1) (0.0025=2) (0.0038=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2) (0.0003=3)

label variable r_ject "% Reject made categorical"

gen b_status  = bag_status

recode b_status  (0.02=1) (0.08=2) (0.9=3)

label variable b_status  "Baggage Status made categorical"

gen c_gs8  = gs8

recode c_gs8  (0.01=1) (0.02=2) (0.03=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.12=1) (0.15=2) (0.18=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"

gen c_gs1  = gs1

recode c_gs1  (0.79=1) (0.83=2) (0.87=3)

label variable c_gs1  "Passenger Group Size 1 made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8
c_gs3 c_gs1

***Maximum Queue Size
```

```
anova max_q active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Working

*Active Station, Cycle Time

anova working active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** WIP

anova wip active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3 c_gs1
```

Appendix A 5

Do-file for CIFC.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\CIFC.dta", clear

gen c_time = cyc_time

recode c_time (1.5666=1) (1.9333=2) (2.76667=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.001=1) (0.002=2) (0.004=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2) (0.0003=3)

label variable r_ject "% Reject made categorical"

gen b_status  = bag_status

recode b_status  (0.02=1) (0.08=2) (0.9=3)

label variable b_status  "Baggage Status made categorical"

gen c_gs8  = gs8

recode c_gs8  (0=1) (0.059701=2) (0.09876=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.130434=1) (0.15671=2) (0.166667=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"
```

```
gen c_gs1  = gs1

recode c_gs1  (0.73456=1) (0.783582=2) (0.869565=3)

label variable c_gs1  "Passenger Group Size 1 made categorical"




*** Throughput

anova thro_put active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8
c_gs3 c_gs1

***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Working

anova working active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject b_status op_exper daily_dmnd c_gs8 c_gs3
c_gs1
```

Appendix A 6

Do-file for EE.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\EE.dta", clear

gen c_time = cyc_time

recode c_time (0.55=1) (0.75=2) (1.3=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.0002=1) (0.0003=2)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2)

label variable r_ject "% Reject made categorical"

gen c_gs8  = gs8
```

```
recode c_gs8  (0.02=1) (0.08=2) (0.1=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.7=1) (0.75=2) (0.88=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"

gen c_gs1  = gs1

recode c_gs1  (0.1=1) (0.17=2) (0.2=3)

label variable c_gs1  "Passenger Group Size 1 made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** %Working

anova working active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** WIP

anova wip active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1
```

Appendix A 7

Do-file for EFB.dta

```
***Prepare Data for ANOVA

use " D:\WORK\THESIS\DATA for THESIS\ANOVA\EFB.dta", clear

gen c_time = cyc_time

recode c_time (0.55=1) (0.75=2) (1.3=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.0002=1) (0.0003=2)
```

```
label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2) (0.0003=3)

label variable r_ject "% Reject made categorical"

gen c_gs8  = gs8

recode c_gs8  (0.01=1) (0.02=2) (0.03=3)

label variable c_gs8  "Passenger Group Size 8 made categorical"

gen c_gs3  = gs3

recode c_gs3  (0.12=1) (0.15=2) (0.18=3)

label variable c_gs3  "Passenger Group Size 3 made categorical"

gen c_gs1  = gs1

recode c_gs1  (0.79=1) (0.83=2) (0.87=3)

label variable c_gs1  "Passenger Group Size 1 made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** Maximum Queue Size

anova max_q active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** %Working

*Active Station, Cycle Time

anova working active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1

*** %Waiting

anova waiting active_sta c_time r_work r_ject op_exper c_gs8 c_gs3 c_gs1
```

Appendix A 8

Do-file for SE.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\SE.dta", clear

gen c_time = cyc_time

recode c_time (0.1166=1) (0.3666=2) (0.9333=3)
```

```
label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.075=1) (0.0875=2) (0.1=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0005=1) (0.0006=2) (0.0007=3)

label variable r_ject "% Reject made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject op_exper

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject op_exper

***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject op_exper

*** %Working

anova working active_sta c_time r_work r_ject op_exper

*** %Waiting

anova waiting active_sta c_time r_work r_ject op_exper

**following were found to be statistically significant: Model; active_sta; c_time &
r_work

*** WIP

anova wip active_sta c_time r_work r_ject op_exper
```

Appendix A 9

Do-file for SFB.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\SFB.dta", clear

gen c_time = cyc_time

recode c_time (0.1166=1) (0.3666=2) (0.9333=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.15=1) (0.18=2) (0.2=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject
```

```
recode r_ject (0.0008=1) (0.001=2) (0.0012=3)

label variable r_ject "% Reject made categorical"


*** Throughput

anova thro_put c_time r_work r_ject op_exper

*** Average Queuing Time

anova ave_q_time c_time r_work r_ject op_exper

***Maximum Queue Size

anova max_q c_time r_work r_ject op_exper

*** %Working

anova working c_time r_work r_ject op_exper

*** %Waiting

anova waiting c_time r_work r_ject op_exper
```

Appendix A 10

Do-file for STR.dta

```
***Prepare Data for ANOVA

use "D:\WORK\THESIS\DATA for THESIS\ANOVA\STR.dta", clear

gen c_time = cyc_time

recode c_time (0.1166=1) (0.3666=2) (0.9333=3)

label variable c_time "Cycle Time made categorical"

gen r_work = rework

recode r_work (0.025=1) (0.03=2) (0.0333=3)

label variable r_work "% Rework made categorical"

gen r_ject = reject

recode r_ject (0.0001=1) (0.0002=2)

label variable r_ject "% Reject made categorical"


*** Throughput

anova thro_put active_sta c_time r_work r_ject op_exper daily_dmnd

*** Average Queuing Time

anova ave_q_time active_sta c_time r_work r_ject op_exper daily_dmnd

***Maximum Queue Size

anova max_q active_sta c_time r_work r_ject op_exper daily_dmnd

*** %Working

*Active Station, Cycle Time

anova working active_sta c_time r_work r_ject op_exper daily_dmnd

*** %Waiting

anova waiting active_sta c_time r_work r_ject op_exper daily_dmnd

*** WIP

anova wip active_sta c_time r_work r_ject op_exper daily_dmnd
```

Appendix A11-ANOVA Results

CHECK-IN ECONOMY

Throughput

Number of obs =	27		R-squared =	0.9522
Root MSE =	24.193		Adj R-squared =	0.8757

Source	Partial SS	df	MS	F	Prob > F
Model	116554.629	16	7284.66433	12.45	0.0001
active_sta	32743.6157	2	16371.8079	27.97	0.0001
c_time	61510.2668	2	30755.1334	52.55	0.0000
r_work	5661.67297	2	2830.83649	4.84	0.0339
r_ject	11792.4055	2	5896.20275	10.07	0.0040
b_status	2377.26671	2	1188.63336	2.03	0.1819
op_exper	294.47668	2	147.23834	0.25	0.7824
daily_dmnd	1138.46232	2	569.231161	0.97	0.4112
c_gs8	767.060365	2	383.530182	0.66	0.5402
c_gs3	0	0			
c_gs1	0	0			
Residual	5853.0063	10	585.30063		
Total	122407.636	26	4707.98598		

Average Queuing Time

Number of obs =	27		R-squared =	0.9642
Root MSE =	46.7085		Adj R-squared =	0.9070

Source	Partial SS	df	MS	F	Prob > F
Model	587881.751	16	36742.6094	16.84	0.0000
active_sta	399623.487	2	199811.744	91.59	0.0000
c_time	95404.0279	2	47702.0139	21.86	0.0002
r_work	14855.9047	2	7427.95237	3.40	0.0745
r_ject	34017.532	2	17008.766	7.80	0.0091
b_status	2540.48694	2	1270.24347	0.58	0.5765
op_exper	825.635314	2	412.817657	0.19	0.8305
daily_dmnd	34046.2629	2	17023.1315	7.80	0.0091
c_gs8	2606.20593	2	1303.10297	0.60	0.5688
c_gs3	0	0			
c_gs1	0	0			
Residual	21816.8046	10	2181.68046		
Total	609698.555	26	23449.9444		

Maximum Queue Size

Number of obs =	27		R-squared =	0.9654	
Root MSE =	97.9332		Adj R-squared =	0.9099	

Source	Partial SS	df	MS	F	Prob > F
Model	2672967.25	16	167060.453	17.42	0.0000
active_sta	945964.741	2	472982.37	49.32	0.0000
c_time	174423.407	2	87211.7037	9.09	0.0056
r_work	14298.2963	2	7149.14815	0.75	0.4992
r_ject	312.518519	2	156.259259	0.02	0.9839
b_status	18247.0322	2	9123.51611	0.95	0.4186
op_exper	20129.6197	2	10064.8099	1.05	0.3857
daily_dmnd	1367967.47	2	683983.735	71.32	0.0000
c_gs8	102562.807	2	51281.4035	5.35	0.0264
c_gs3	0	0			
c_gs1	0	0			
Residual	95909.0439	10	9590.90439		
Total	2768876.3	26	106495.242		

%Working

Number of obs =	27		R-squared =	0.9549	
Root MSE =	6.24515		Adj R-squared =	0.8829	

Source	Partial SS	df	MS	F	Prob > F
Model	8266.85347	16	516.678342	13.25	0.0001
active_sta	5537.50086	2	2768.75043	70.99	0.0000
c_time	1242.6077	2	621.303848	15.93	0.0008
r_work	234.68186	2	117.34093	3.01	0.0949
r_ject	626.285489	2	313.142745	8.03	0.0083
b_status	63.4545242	2	31.7272621	0.81	0.4706
op_exper	4.43333042	2	2.21666521	0.06	0.9451
daily_dmnd	415.84891	2	207.924455	5.33	0.0266
c_gs8	100.783886	2	50.3919428	1.29	0.3169
c_gs3	0	0			
c_gs1	0	0			
Residual	390.018717	10	39.0018717		
Total	8656.87218	26	332.956622		

%Waiting

Number of obs = 27   R-squared = 0.9549
Root MSE = 6.24515   Adj R-squared = 0.8829

Source	Partial SS	df	MS	F	Prob > F
Model	8266.85081	16	516.678176	13.25	0.0001
active_sta	5537.49814	2	2768.74907	70.99	0.0000
c_time	1242.60776	2	621.303878	15.93	0.0008
r_work	234.681811	2	117.340906	3.01	0.0949
r_ject	626.285589	2	313.142794	8.03	0.0083
b_status	63.454501	2	31.7272505	0.81	0.4706
op_exper	4.43334536	2	2.21667268	0.06	0.9451
daily_dmnd	415.848867	2	207.924433	5.33	0.0266
c_gs8	100.783927	2	50.3919633	1.29	0.3169
c_gs3	0	0			
c_gs1	0	0			
Residual	390.018937	10	39.0018937		
Total	8656.86975	26	332.956529		

WIP

Number of obs = 27   R-squared = 0.9403
Root MSE = 199.724   Adj R-squared = 0.8448

Source	Partial SS	df	MS	F	Prob > F
Model	6283843.66	16	392740.229	9.85	0.0004
active_sta	4010648.96	2	2005324.48	50.27	0.0000
c_time	864330.963	2	432165.481	10.83	0.0031
r_work	188362.296	2	94181.1481	2.36	0.1446
r_ject	310400.519	2	155200.259	3.89	0.0563
b_status	71469.4208	2	35734.7104	0.90	0.4387
op_exper	29910.3097	2	14955.1548	0.37	0.6966
daily_dmnd	704070.17	2	352035.085	8.83	0.0062
c_gs8	211737.64	2	105868.82	2.65	0.1190
c_gs3	0	0			
c_gs1	0	0			
Residual	398898.415	10	39889.8415		
Total	6682742.07	26	257028.541		

CHECK-IN ECONOMY SELF SERVICE

Throughput

Number of obs = 27 R-squared = 0.9627
Root MSE = 4.62051 Adj R-squared = 0.9461

Source	Partial SS	df	MS	F	Prob > F
Model	9904.97672	8	1238.12209	57.99	0.0000
active_sta	8163.66072	2	4081.83036	191.19	0.0000
c_time	14.5185185	2	7.25925926	0.34	0.7162
r_ject	14.5185185	2	7.25925926	0.34	0.7162
daily_dmnd	1712.27896	2	856.139478	40.10	0.0000
Residual	384.284726	18	21.3491514		
Total	10289.2614	26	395.740825		

%Working

Number of obs = 27 R-squared = 0.9429
Root MSE = 1.04387 Adj R-squared = 0.9175

Source	Partial SS	df	MS	F	Prob > F
Model	323.86625	8	40.4832813	37.15	0.0000
active_sta	87.7638262	2	43.8819131	40.27	0.0000
c_time	207.875436	2	103.937718	95.38	0.0000
r_ject	12.1642725	2	6.08213627	5.58	0.0130
daily_dmnd	16.0627153	2	8.03135766	7.37	0.0046
Residual	19.6140754	18	1.08967086		
Total	343.480326	26	13.2107818		

%Waiting

```
                 Number of obs =      27     R-squared     =  0.9429
                 Root MSE      = 1.04387     Adj R-squared =  0.9175

      Source | Partial SS    df       MS           F     Prob > F
  -----------+----------------------------------------------------
       Model | 323.865998     8  40.4832498      37.15     0.0000
             |
  active_sta | 87.7636344     2  43.8818172      40.27     0.0000
      c_time | 207.875371     2  103.937686      95.38     0.0000
      r_ject | 12.1642669     2  6.08213345       5.58     0.0130
  daily_dmnd |  16.062726     2  8.03136299       7.37     0.0046
             |
    Residual | 19.6140716    18  1.08967065
  -----------+----------------------------------------------------
       Total |  343.48007    26  13.2107719
```

CHECK-IN ECONOMY BAG DROP

Throughput

```
                 Number of obs =      27     R-squared     =  0.9558
                 Root MSE      = 20.7804     Adj R-squared =  0.9116

      Source | Partial SS    df       MS           F     Prob > F
  -----------+----------------------------------------------------
       Model | 121417.176    13  9339.78281      21.63     0.0000
             |
  active_sta | 68058.9905     2  34029.4953      78.80     0.0000
      c_time |   14783.79     2  7391.89501      17.12     0.0002
      r_work | 10846.5908     2  5423.29541      12.56     0.0009
      r_ject | 11970.2794     2  5985.13972      13.86     0.0006
    op_exper | 15194.1467     2  7597.07335      17.59     0.0002
  daily_dmnd | 1160.72914     1  1160.72914       2.69     0.1251
       c_gs8 | 530.344277     2  265.172139       0.61     0.5561
       c_gs3 |          0     0
       c_gs1 |          0     0
             |
    Residual | 5613.69887    13   431.82299
  -----------+----------------------------------------------------
       Total | 127030.875    26   4885.8029
```

Average Queuing Time

Number of obs =	27	R-squared =	0.9885	
Root MSE =	32.3559	Adj R-squared =	0.9770	

Source	Partial SS	df	MS	F	Prob > F
Model	1168236.36	13	89864.3353	85.84	0.0000
active_sta	374090.695	2	187045.348	178.67	0.0000
c_time	692030.36	2	346015.18	330.51	0.0000
r_work	3417.93799	2	1708.96899	1.63	0.2331
r_ject	24641.2795	2	12320.6397	11.77	0.0012
op_exper	70720.8708	2	35360.4354	33.78	0.0000
daily_dmnd	4690.46524	1	4690.46524	4.48	0.0541
c_gs8	2314.24071	2	1157.12036	1.11	0.3603
c_gs3	0	0			
c_gs1	0	0			
Residual	13609.7354	13	1046.90272		
Total	1181846.09	26	45455.619		

Maximum Queue Size

Number of obs =	27	R-squared =	0.9968	
Root MSE =	17.2612	Adj R-squared =	0.9935	

Source	Partial SS	df	MS	F	Prob > F
Model	1188674.07	13	91436.467	306.89	0.0000
active_sta	237827.63	2	118913.815	399.11	0.0000
c_time	405455.407	2	202727.704	680.41	0.0000
r_work	1283.85185	2	641.925926	2.15	0.1555
r_ject	301.851852	2	150.925926	0.51	0.6140
op_exper	531159.183	2	265579.591	891.36	0.0000
daily_dmnd	27489.3384	1	27489.3384	92.26	0.0000
c_gs8	372.805225	2	186.402612	0.63	0.5503
c_gs3	0	0			
c_gs1	0	0			
Residual	3873.33598	13	297.948921		
Total	1192547.41	26	45867.208		

%Working

```
                    Number of obs =      27     R-squared     =  0.9839
                    Root MSE      = 4.75126     Adj R-squared =  0.9678

          Source | Partial SS    df       MS           F     Prob > F
      -----------+----------------------------------------------------
           Model |  17958.863    13    1381.451      61.20     0.0000
                 |
      active_sta | 5437.28542     2  2718.64271     120.43     0.0000
          c_time | 10830.2254     2  5415.11272     239.88     0.0000
          r_work | 105.639478     2   52.819739       2.34     0.1355
          r_ject | 465.172843     2  232.586422      10.30     0.0021
        op_exper | 1116.53578     2  558.267892      24.73     0.0000
     daily_dmnd  | 84.2888004     1  84.2888004       3.73     0.0754
           c_gs8 | 2.82372264     2  1.41186132       0.06     0.9397
           c_gs3 |          0     0
           c_gs1 |          0     0
                 |
        Residual | 293.468526    13   22.574502
      -----------+----------------------------------------------------
           Total | 18252.3315    26   702.01275
```

%Waiting

```
                    Number of obs =      27     R-squared     =  0.9839
                    Root MSE      = 4.75126     Adj R-squared =  0.9678

          Source | Partial SS    df       MS           F     Prob > F
      -----------+----------------------------------------------------
           Model | 17958.8609    13  1381.45084      61.20     0.0000
                 |
      active_sta | 5437.28336     2  2718.64168     120.43     0.0000
          c_time | 10830.2252     2  5415.11259     239.88     0.0000
          r_work | 105.639443     2  52.8197215       2.34     0.1355
          r_ject | 465.172783     2  232.586391      10.30     0.0021
        op_exper | 1116.53608     2  558.268038      24.73     0.0000
     daily_dmnd  | 84.2887688     1  84.2887688       3.73     0.0754
           c_gs8 | 2.82372047     2  1.41186024       0.06     0.9397
           c_gs3 |          0     0
           c_gs1 |          0     0
                 |
        Residual | 293.468456    13  22.5744966
      -----------+----------------------------------------------------
           Total | 18252.3293    26  702.012667
```

WIP

	Number of obs =	27		R-squared =	0.8568
	Root MSE =	87.8561		Adj R-squared =	0.7135

Source	Partial SS	df	MS	F	Prob > F
Model	600135.849	13	46164.2961	5.98	0.0014
active_sta	206328.074	2	103164.037	13.37	0.0007
c_time	145832.074	2	72916.037	9.45	0.0029
r_work	88680.0741	2	44340.037	5.74	0.0163
r_ject	104848.074	2	52424.037	6.79	0.0096
op_exper	44720.0714	2	22360.0357	2.90	0.0911
daily_dmnd	97.5808081	1	97.5808081	0.01	0.9122
c_gs8	7129.91634	2	3564.95817	0.46	0.6401
c_gs3	0	0			
c_gs1	0	0			
Residual	100343.114	13	7718.70106		
Total	700478.963	26	26941.4986		

CHECK-IN BUSINESS CLASS

Throughput

Number of obs = 27 R-squared = 0.9830
Root MSE = 40.9225 Adj R-squared = 0.9558

Source	Partial SS	df	MS	F	Prob > F
Model	968189.316	16	60511.8323	36.13	0.0000
active_sta	942595.553	2	471297.777	281.43	0.0000
c_time	1606.10098	2	803.05049	0.48	0.6326
r_work	1105.26194	2	552.630972	0.33	0.7265
r_ject	1127.76194	2	563.88097	0.34	0.7219
b_status	1233.38765	2	616.693825	0.37	0.7009
op_exper	477.023422	2	238.511711	0.14	0.8690
daily_dmnd	15806.8602	2	7903.43012	4.72	0.0360
c_gs8	3880.68743	2	1940.34371	1.16	0.3527
c_gs3	0	0			
c_gs1	0	0			
Residual	16746.4944	10	1674.64944		
Total	984935.811	26	37882.1466		

Average Queuing Time

Number of obs = 27 R-squared = 0.8755
Root MSE = 62.748 Adj R-squared = 0.6762

Source	Partial SS	df	MS	F	Prob > F
Model	276806.558	16	17300.4099	4.39	0.0111
active_sta	146102.403	2	73051.2016	18.55	0.0004
c_time	35502.1759	2	17751.088	4.51	0.0402
r_work	35448.9336	2	17724.4668	4.50	0.0404
r_ject	35459.1202	2	17729.5601	4.50	0.0403
b_status	728.214033	2	364.107016	0.09	0.9124
op_exper	4432.75466	2	2216.37733	0.56	0.5866
daily_dmnd	15076.0473	2	7538.02363	1.91	0.1977
c_gs8	4896.0644	2	2448.0322	0.62	0.5565
c_gs3	0	0			
c_gs1	0	0			
Residual	39373.1197	10	3937.31197		
Total	316179.678	26	12160.7568		

Maximum Queue Size

Number of obs = 27 R-squared = 0.8961
Root MSE = 43.1915 Adj R-squared = 0.7298

Source	Partial SS	df	MS	F	Prob > F
Model	160879.43	16	10054.9644	5.39	0.0051
active_sta	118915.852	2	59457.9259	31.87	0.0000
c_time	10748.963	2	5374.48148	2.88	0.1028
r_work	9931.62963	2	4965.81481	2.66	0.1183
r_ject	10172.7407	2	5086.37037	2.73	0.1135
b_status	177.139991	2	88.5699957	0.05	0.9538
op_exper	921.353081	2	460.676541	0.25	0.7858
daily_dmnd	9843.3196	2	4921.6598	2.64	0.1202
c_gs8	1112.02584	2	556.012918	0.30	0.7486
c_gs3	0	0			
c_gs1	0	0			
Residual	18655.0883	10	1865.50883		
Total	179534.519	26	6905.17379		

%Working

Number of obs = 27 R-squared = 0.9898
Root MSE = 5.21743 Adj R-squared = 0.9734

Source	Partial SS	df	MS	F	Prob > F
Model	26337.7077	16	1646.10673	60.47	0.0000
active_sta	23635.2846	2	11817.6423	434.13	0.0000
c_time	1331.87746	2	665.938731	24.46	0.0001
r_work	461.514238	2	230.757119	8.48	0.0070
r_ject	495.01572	2	247.50786	9.09	0.0056
b_status	21.787976	2	10.893988	0.40	0.6805
op_exper	.406413754	2	.203206877	0.01	0.9926
daily_dmnd	378.432009	2	189.216005	6.95	0.0128
c_gs8	24.0781861	2	12.039093	0.44	0.6546
c_gs3	0	0			
c_gs1	0	0			
Residual	272.216112	10	27.2216112		
Total	26609.9239	26	1023.45861		

%Waiting

Number of obs = 27			R-squared = 0.9898		
Root MSE = 5.21744			Adj R-squared = 0.9734		

Source	Partial SS	df	MS	F	Prob > F
Model	26337.7071	16	1646.1067	60.47	0.0000
active_sta	23635.2842	2	11817.6421	434.13	0.0000
c_time	1331.87718	2	665.938588	24.46	0.0001
r_work	461.514211	2	230.757106	8.48	0.0070
r_ject	495.015681	2	247.507841	9.09	0.0056
b_status	21.7879581	2	10.893979	0.40	0.6805
op_exper	.406417665	2	.203208832	0.01	0.9926
daily_dmnd	378.432134	2	189.216067	6.95	0.0128
c_gs8	24.078177	2	12.0390885	0.44	0.6546
c_gs3	0	0			
c_gs1	0	0			
Residual	272.216341	10	27.2216341		
Total	26609.9235	26	1023.4586		

WIP

Number of obs = 27			R-squared = 0.6312		
Root MSE = 21.4589			Adj R-squared = 0.0410		

Source	Partial SS	df	MS	F	Prob > F
Model	7879.67635	16	492.479772	1.07	0.4717
active_sta	1048.96296	2	524.481481	1.14	0.3584
c_time	1048.96296	2	524.481481	1.14	0.3584
r_work	1048.96296	2	524.481481	1.14	0.3584
r_ject	1048.96296	2	524.481481	1.14	0.3584
b_status	850.689037	2	425.344519	0.92	0.4284
op_exper	839.827546	2	419.913773	0.91	0.4327
daily_dmnd	920.953877	2	460.476939	1.00	0.4019
c_gs8	920.953877	2	460.476939	1.00	0.4019
c_gs3	0	0			
c_gs1	0	0			
Residual	4604.84217	10	460.484217		
Total	12484.5185	26	480.173789		

CHECK-IN FIRST CLASS

Throughput

Number of obs =	27	R-squared =	0.9879
Root MSE =	6.73278	Adj R-squared =	0.9739

Source	Partial SS	df	MS	F	Prob > F
Model	44535.4218	14	3181.10156	70.18	0.0000
active_sta	43597.0486	2	21798.5243	480.88	0.0000
c_time	.960000203	2	.480000102	0.01	0.9895
r_work	3.44888926	2	1.72444463	0.04	0.9628
r_ject	3.44888926	2	1.72444463	0.04	0.9628
b_status	.960000203	2	.480000102	0.01	0.9895
op_exper	3.44888926	2	1.72444463	0.04	0.9628
daily_dmnd	926.106517	2	463.053259	10.22	0.0026
c_gs8	0	0			
c_gs3	0	0			
c_gs1	0	0			
Residual	543.964511	12	45.3303759		
Total	45079.3863	26	1733.82255		

Average Queuing Time

Number of obs =	27	R-squared =	0.6981
Root MSE =	2.12344	Adj R-squared =	0.3460

Source	Partial SS	df	MS	F	Prob > F
Model	125.136595	14	8.93832823	1.98	0.1208
active_sta	46.3441437	2	23.1720719	5.14	0.0244
c_time	17.2783022	2	8.63915108	1.92	0.1896
r_work	17.2670195	2	8.63350977	1.91	0.1898
r_ject	17.2688574	2	8.63442869	1.91	0.1898
b_status	5.56785859	2	2.78392929	0.62	0.5556
op_exper	5.56827635	2	2.78413818	0.62	0.5556
daily_dmnd	15.8421375	2	7.92106877	1.76	0.2142
c_gs8	0	0			
c_gs3	0	0			
c_gs1	0	0			
Residual	54.10789	12	4.50899083		
Total	179.244485	26	6.89401866		

Maximum Queue Size

Number of obs =	27		R-squared =	0.7544	
Root MSE =	2.17307		Adj R-squared =	0.4679	

Source	Partial SS	df	MS	F	Prob > F
Model	174.074074	14	12.4338624	2.63	0.0503
active_sta	118.518519	2	59.2592593	12.55	0.0011
c_time	9.40740741	2	4.7037037	1.00	0.3979
r_work	9.40740741	2	4.7037037	1.00	0.3979
r_ject	9.40740741	2	4.7037037	1.00	0.3979
b_status	1.40740741	2	.703703704	0.15	0.8631
op_exper	1.40740741	2	.703703704	0.15	0.8631
daily_dmnd	24.5185185	2	12.2592593	2.60	0.1156
c_gs8	0	0			
c_gs3	0	0			
c_gs1	0	0			
Residual	56.6666667	12	4.72222222		
Total	230.740741	26	8.87464387		

%Working

Number of obs =	27		R-squared =	0.9785	
Root MSE =	1.6635		Adj R-squared =	0.9534	

Source	Partial SS	df	MS	F	Prob > F
Model	1512.28277	14	108.020198	39.04	0.0000
active_sta	1241.98476	2	620.99238	224.41	0.0000
c_time	144.327008	2	72.163504	26.08	0.0000
r_work	38.7124026	2	19.3562013	6.99	0.0097
r_ject	37.9468312	2	18.9734156	6.86	0.0103
b_status	.704770537	2	.352385268	0.13	0.8816
op_exper	1.0125115	2	.506255749	0.18	0.8351
daily_dmnd	47.5944911	2	23.7972456	8.60	0.0048
c_gs8	0	0			
c_gs3	0	0			
c_gs1	0	0			
Residual	33.2068844	12	2.76724037		
Total	1545.48966	26	59.44191		

%Waiting

	Number of obs =	27	R-squared =	0.9785	
	Root MSE =	1.6635	Adj R-squared =	0.9534	

Source	Partial SS	df	MS	F	Prob > F
Model	1512.28338	14	108.020241	39.04	0.0000
active_sta	1241.98518	2	620.992589	224.41	0.0000
c_time	144.327159	2	72.1635794	26.08	0.0000
r_work	38.7124168	2	19.3562084	6.99	0.0097
r_ject	37.9469648	2	18.9734824	6.86	0.0103
b_status	.704770355	2	.352385177	0.13	0.8816
op_exper	1.01252361	2	.506261805	0.18	0.8351
daily_dmnd	47.5943669	2	23.7971835	8.60	0.0048
c_gs8	0	0			
c_gs3	0	0			
c_gs1	0	0			
Residual	33.206875	12	2.76723958		
Total	1545.49025	26	59.4419329		

EMIGRATION ECONOMY

Throughput

Number of obs = 27	R-squared = 0.9181
Root MSE = 118.004	Adj R-squared = 0.8670

Source	Partial SS	df	MS	F	Prob > F
Model	2498379.27	10	249837.927	17.94	0.0000
active_sta	1803646.46	2	901823.229	64.76	0.0000
c_time	609926.866	2	304963.433	21.90	0.0000
r_work	78912.9521	1	78912.9521	5.67	0.0301
r_ject	1929.11217	1	1929.11217	0.14	0.7146
op_exper	1031.31849	2	515.659244	0.04	0.9637
c_gs8	2749.60806	2	1374.80403	0.10	0.9065
c_gs3	0	0			
c_gs1	0	0			
Residual	222800.559	16	13925.035		
Total	2721179.83	26	104660.763		

Average Queuing Time

Number of obs = 27	R-squared = 0.8775
Root MSE = 40.2273	Adj R-squared = 0.8009

Source	Partial SS	df	MS	F	Prob > F
Model	185439.209	10	18543.9209	11.46	0.0000
active_sta	66132.0067	2	33066.0034	20.43	0.0000
c_time	95577.4935	2	47788.7468	29.53	0.0000
r_work	22926.3479	1	22926.3479	14.17	0.0017
r_ject	437.119332	1	437.119332	0.27	0.6104
op_exper	190.169719	2	95.0848597	0.06	0.9431
c_gs8	118.71645	2	59.3582251	0.04	0.9641
c_gs3	0	0			
c_gs1	0	0			
Residual	25891.7564	16	1618.23477		
Total	211330.966	26	8128.11406		

Maximum Queue Size

Number of obs = 27			R-squared = 0.8029		
Root MSE = 218.182			Adj R-squared = 0.6797		

Source	Partial SS	df	MS	F	Prob > F
Model	3102529.38	10	310252.938	6.52	0.0005
active_sta	1350071.63	2	675035.815	14.18	0.0003
c_time	1000760.52	2	500380.259	10.51	0.0012
r_work	579496.963	1	579496.963	12.17	0.0030
r_ject	133798.785	1	133798.785	2.81	0.1131
op_exper	31526.5658	2	15763.2829	0.33	0.7229
c_gs8	25461.9198	2	12730.9599	0.27	0.7687
c_gs3	0	0			
c_gs1	0	0			
Residual	761655.36	16	47603.46		
Total	3864184.74	26	148622.49		

%Working

Number of obs = 27			R-squared = 0.9507		
Root MSE = 7.77314			Adj R-squared = 0.9198		

Source	Partial SS	df	MS	F	Prob > F
Model	18630.6035	10	1863.06035	30.83	0.0000
active_sta	16016.2274	2	8008.11368	132.54	0.0000
c_time	2494.7734	2	1247.3867	20.64	0.0000
r_work	81.8462145	1	81.8462145	1.35	0.2615
r_ject	.506935035	1	.506935035	0.01	0.9282
op_exper	24.7410399	2	12.3705199	0.20	0.8170
c_gs8	12.0346858	2	6.0173429	0.10	0.9058
c_gs3	0	0			
c_gs1	0	0			
Residual	966.74635	16	60.4216469		
Total	19597.3498	26	753.744223		

%Waiting

	Number of obs = 27			R-squared = 0.9507	
	Root MSE = 7.77314			Adj R-squared = 0.9198	

Source	Partial SS	df	MS	F	Prob > F
Model	18630.6018	10	1863.06018	30.83	0.0000
active_sta	16016.2267	2	8008.11333	132.54	0.0000
c_time	2494.77253	2	1247.38626	20.64	0.0000
r_work	81.8462138	1	81.8462138	1.35	0.2615
r_ject	.506937521	1	.506937521	0.01	0.9282
op_exper	24.7409869	2	12.3704935	0.20	0.8170
c_gs8	12.0346427	2	6.01732133	0.10	0.9058
c_gs3	0	0			
c_gs1	0	0			
Residual	966.746234	16	60.4216396		
Total	19597.348	26	753.744155		

WIP

	Number of obs = 27			R-squared = 0.6684	
	Root MSE = 326.744			Adj R-squared = 0.4611	

Source	Partial SS	df	MS	F	Prob > F
Model	3442986.36	10	344298.636	3.22	0.0182
active_sta	317343.185	2	158671.593	1.49	0.2558
c_time	2232236.74	2	1116118.37	10.45	0.0012
r_work	765884.463	1	765884.463	7.17	0.0165
r_ject	86955.3711	1	86955.3711	0.81	0.3802
op_exper	24887.1604	2	12443.5802	0.12	0.8907
c_gs8	24884.2067	2	12442.1034	0.12	0.8907
c_gs3	0	0			
c_gs1	0	0			
Residual	1708186.15	16	106761.635		
Total	5151172.52	26	198122.02		

EMIGRATION FIRST/BUSINESS CLASS

Throughput

Number of obs = 27 R-squared = 0.9386
Root MSE = 63.0467 Adj R-squared = 0.8936

Source	Partial SS	df	MS	F	Prob > F
Model	911482.579	11	82862.0526	20.85	0.0000
active_sta	900055.171	2	450027.586	113.22	0.0000
c_time	2263.06019	2	1131.53009	0.28	0.7562
r_work	929.185185	1	929.185185	0.23	0.6357
r_ject	317.211653	2	158.605827	0.04	0.9610
op_exper	1429.90303	2	714.951516	0.18	0.8372
c_gs8	6518.53741	2	3259.26871	0.82	0.4592
c_gs3	0	0			
c_gs1	0	0			
Residual	59623.2035	15	3974.88023		
Total	971105.782	26	37350.2224		

Average Queuing Time

Number of obs = 27 R-squared = 0.4654
Root MSE = .011805 Adj R-squared = 0.0734

Source	Partial SS	df	MS	F	Prob > F
Model	.001820055	11	.00016546	1.19	0.3707
active_sta	.000227358	2	.000113679	0.82	0.4610
c_time	.00059682	2	.00029841	2.14	0.1520
r_work	.000115808	1	.000115808	0.83	0.3764
r_ject	.000219494	2	.000109747	0.79	0.4729
op_exper	.000282662	2	.000141331	1.01	0.3863
c_gs8	.000377043	2	.000188521	1.35	0.2883
c_gs3	0	0			
c_gs1	0	0			
Residual	.002090472	15	.000139365		
Total	.003910528	26	.000150405		

Maximum Queue Size

```
                        Number of obs =      27     R-squared     =  0.4020
                        Root MSE      = 1.51573     Adj R-squared = -0.0365
```

Source	Partial SS	df	MS	F	Prob > F
Model	23.1681887	11	2.10619898	0.92	0.5487
active_sta	.962962963	2	.481481481	0.21	0.8133
c_time	4.74074074	2	2.37037037	1.03	0.3803
r_work	.907407407	1	.907407407	0.39	0.5392
r_ject	3.67011274	2	1.83505637	0.80	0.4681
op_exper	.853373922	2	.426686961	0.19	0.8324
c_gs8	10.7494778	2	5.37473891	2.34	0.1305
c_gs3	0	0			
c_gs1	0	0			
Residual	34.4614409	15	2.29742939		
Total	57.6296296	26	2.21652422		

%Working

```
                        Number of obs =      27     R-squared     =  0.9247
                        Root MSE      = 5.67681     Adj R-squared =  0.8694
```

Source	Partial SS	df	MS	F	Prob > F
Model	5932.76734	11	539.342486	16.74	0.0000
active_sta	4041.01297	2	2020.50649	62.70	0.0000
c_time	1676.29137	2	838.145687	26.01	0.0000
r_work	203.839415	1	203.839415	6.33	0.0238
r_ject	.877922384	2	.438961192	0.01	0.9865
op_exper	3.48864548	2	1.74432274	0.05	0.9475
c_gs8	4.47875399	2	2.23937699	0.07	0.9332
c_gs3	0	0			
c_gs1	0	0			
Residual	483.392173	15	32.2261449		
Total	6416.15952	26	246.775366		

%Waiting

Number of obs = 27	R-squared = 0.9886
Root MSE = 5.67681	Adj R-squared = 0.9803

Source	Partial SS	df	MS	F	Prob > F
Model	41966.3189	11	3815.1199	118.39	0.0000
active_sta	40074.5645	2	20037.2822	621.77	0.0000
c_time	1676.29133	2	838.145667	26.01	0.0000
r_work	203.83945	1	203.83945	6.33	0.0238
r_ject	.877920731	2	.438960366	0.01	0.9865
op_exper	3.48866396	2	1.74433198	0.05	0.9475
c_gs8	4.47874217	2	2.23937109	0.07	0.9332
c_gs3	0	0			
c_gs1	0	0			
Residual	483.39202	15	32.2261346		
Total	42449.7109	26	1632.68119		

SECURITY CHECK ECONOMY

Throughput

Number of obs =	27	R-squared =	0.9231
Root MSE =	391.393	Adj R-squared =	0.8824

Source	Partial SS	df	MS	F	Prob > F
Model	31270689.1	9	3474521.01	22.68	0.0000
active_sta	5563251.04	1	5563251.04	36.32	0.0000
c_time	23889274.1	2	11944637	77.97	0.0000
r_work	1696018.06	2	848009.028	5.54	0.0141
r_ject	67309.9206	2	33654.9603	0.22	0.8050
op_exper	66379.8095	2	33189.9048	0.22	0.8074
Residual	2604202.04	17	153188.355		
Total	33874891.2	26	1302880.43		

Average Queuing Time

Number of obs =	27	R-squared =	0.7351
Root MSE =	85.8956	Adj R-squared =	0.5948

Source	Partial SS	df	MS	F	Prob > F
Model	347980.684	9	38664.5204	5.24	0.0017
active_sta	429.721719	1	429.721719	0.06	0.8122
c_time	314138.447	2	157069.223	21.29	0.0000
r_work	33349.404	2	16674.702	2.26	0.1348
r_ject	13.3479548	2	6.67397739	0.00	0.9991
op_exper	51.095458	2	25.547729	0.00	0.9965
Residual	125426.994	17	7378.05848		
Total	473407.678	26	18207.9876		

Maximum Queue Size

Number of obs =	27	R-squared =	0.6049
Root MSE =	762.944	Adj R-squared =	0.3957

Source	Partial SS	df	MS	F	Prob > F
Model	15148279.3	9	1683142.15	2.89	0.0284
active_sta	1190821.5	1	1190821.5	2.05	0.1708
c_time	10531340.2	2	5265670.11	9.05	0.0021
r_work	3335846	2	1667923	2.87	0.0846
r_ject	46358.0635	2	23179.0317	0.04	0.9611
op_exper	39380.9524	2	19690.4762	0.03	0.9668
Residual	9895425.33	17	582083.843		
Total	25043704.7	26	963219.41		

%Working

	Number of obs =	27	R-squared =	0.9831	
	Root MSE =	4.95293	Adj R-squared =	0.9742	

Source	Partial SS	df	MS	F	Prob > F
Model	24266.5895	9	2696.28772	109.91	0.0000
active_sta	1096.72587	1	1096.72587	44.71	0.0000
c_time	22897.3489	2	11448.6744	466.69	0.0000
r_work	270.555162	2	135.277581	5.51	0.0143
r_ject	1.2233336	2	.611666802	0.02	0.9754
op_exper	.694606225	2	.347303112	0.01	0.9860
Residual	417.036043	17	24.5315319		
Total	24683.6255	26	949.370211		

%Waiting

	Number of obs =	27	R-squared =	0.9831	
	Root MSE =	4.95293	Adj R-squared =	0.9742	

Source	Partial SS	df	MS	F	Prob > F
Model	24266.5917	9	2696.28796	109.91	0.0000
active_sta	1096.72651	1	1096.72651	44.71	0.0000
c_time	22897.3503	2	11448.6751	466.69	0.0000
r_work	270.555325	2	135.277662	5.51	0.0143
r_ject	1.22333686	2	.611668429	0.02	0.9754
op_exper	.694612447	2	.347306224	0.01	0.9860
Residual	417.036171	17	24.5315395		
Total	24683.6278	26	949.370302		

WIP

	Number of obs =	27	R-squared =	0.7300	
	Root MSE =	564.584	Adj R-squared =	0.5871	

Source	Partial SS	df	MS	F	Prob > F
Model	14654438.3	9	1628270.93	5.11	0.0019
active_sta	222594.241	1	222594.241	0.70	0.4149
c_time	10727037	2	5363518.48	16.83	0.0001
r_work	3585195.85	2	1792597.93	5.62	0.0134
r_ject	47463.6556	2	23731.8278	0.07	0.9286
op_exper	57180.1	2	28590.05	0.09	0.9146
Residual	5418827.73	17	318754.573		
Total	20073266.1	26	772048.695		

SECURITY CHECK FIRST/BUSINESS CLASS

Throughput

Number of obs =	27	R-squared =	0.0798
Root MSE =	105.5	Adj R-squared =	-0.3292

Source	Partial SS	df	MS	F	Prob > F
Model	17362.279	8	2170.28487	0.19	0.9881
c_time	5440.07407	2	2720.03704	0.24	0.7857
r_work	1362.74074	2	681.37037	0.06	0.9408
r_ject	4942.5012	2	2471.2506	0.22	0.8031
op_exper	5874.05676	2	2937.02838	0.26	0.7710
Residual	200346.017	18	11130.3343		
Total	217708.296	26	8373.39601		

Average Queuing Time

Number of obs =	27	R-squared =	0.5468
Root MSE =	9.19514	Adj R-squared =	0.3453

Source	Partial SS	df	MS	F	Prob > F
Model	1836.06918	8	229.508648	2.71	0.0374
c_time	1108.62056	2	554.310281	6.56	0.0073
r_work	258.11607	2	129.058035	1.53	0.2442
r_ject	308.914273	2	154.457137	1.83	0.1895
op_exper	145.003796	2	72.5018978	0.86	0.4408
Residual	1521.91186	18	84.5506587		
Total	3357.98104	26	129.153117		

Maximum Queue Size

```
                   Number of obs =         27     R-squared     =  0.5600
                   Root MSE      =    32.7274     Adj R-squared =  0.3645

         Source │  Partial SS         df         MS        F    Prob > F
      ──────────┼──────────────────────────────────────────────────────
          Model │  24538.1462          8   3067.26828     2.86     0.0304
                │
         c_time │  15338.7407          2   7669.37037     7.16     0.0052
         r_work │   3838.2963          2   1919.14815     1.79     0.1951
         r_ject │  3044.14622          2   1522.07311     1.42     0.2673
       op_exper │    2021.924          2     1010.962     0.94     0.4076
                │
       Residual │  19279.4834         18   1071.08241
      ──────────┼──────────────────────────────────────────────────────
          Total │  43817.6296         26   1685.29345
```

%Working

```
                   Number of obs =         27     R-squared     =  0.9660
                   Root MSE      =    3.47108     Adj R-squared =  0.9509

         Source │  Partial SS         df         MS        F    Prob > F
      ──────────┼──────────────────────────────────────────────────────
          Model │   6156.8458          8   769.605725    63.88     0.0000
                │
         c_time │  6110.80427          2   3055.40214   253.59     0.0000
         r_work │  5.98120607          2   2.99060304     0.25     0.7828
         r_ject │  15.6470594          2   7.82352969     0.65     0.5342
       op_exper │  23.5787969          2   11.7893985     0.98     0.3950
                │
       Residual │  216.870768         18    12.048376
      ──────────┼──────────────────────────────────────────────────────
          Total │  6373.71656         26   245.142945
```

%Waiting

```
                   Number of obs =         27     R-squared     =  0.9660
                   Root MSE      =    3.47108     Adj R-squared =  0.9509

         Source │  Partial SS         df         MS        F    Prob > F
      ──────────┼──────────────────────────────────────────────────────
          Model │  6156.84573          8   769.605716    63.88     0.0000
                │
         c_time │  6110.80422          2   3055.40211   253.59     0.0000
         r_work │  5.98120607          2   2.99060304     0.25     0.7828
         r_ject │  15.6470402          2   7.82352008     0.65     0.5342
       op_exper │  23.5788033          2   11.7894017     0.98     0.3950
                │
       Residual │  216.870827         18   12.0483793
      ──────────┼──────────────────────────────────────────────────────
          Total │  6373.71656         26   245.142944
```

SECURITY TRANSFER PASSENGERS

Throughput

	Number of obs = 27			R-squared = 0.8491	
	Root MSE = 870.801			Adj R-squared = 0.7385	

Source	Partial SS	df	MS	F	Prob > F
Model	64020553.5	11	5820050.31	7.68	0.0002
active_sta	41556922.4	2	20778461.2	27.40	0.0000
c_time	11400929.3	2	5700464.63	7.52	0.0055
r_work	10613329	2	5306664.51	7.00	0.0071
r_ject	3287.75702	1	3287.75702	0.00	0.9484
op_exper	29172.2036	2	14586.1018	0.02	0.9810
daily_dmnd	394439.774	2	197219.887	0.26	0.7744
Residual	11374406.4	15	758293.757		
Total	75394959.8	26	2899806.15		

Average Queuing Time

	Number of obs = 27			R-squared = 0.8354	
	Root MSE = 124.011			Adj R-squared = 0.7148	

Source	Partial SS	df	MS	F	Prob > F
Model	1171190.49	11	106471.863	6.92	0.0004
active_sta	667303.682	2	333651.841	21.70	0.0000
c_time	406163.226	2	203081.613	13.21	0.0005
r_work	92355.6503	2	46177.8251	3.00	0.0800
r_ject	606.807106	1	606.807106	0.04	0.8452
op_exper	244.298628	2	122.149314	0.01	0.9921
daily_dmnd	4463.44735	2	2231.72367	0.15	0.8661
Residual	230682.421	15	15378.8281		
Total	1401872.91	26	53918.1889		

Maximum Queue Size

Number of obs = 27 R-squared = 0.8791
Root MSE = 757.291 Adj R-squared = 0.7904

Source	Partial SS	df	MS	F	Prob > F
Model	62532949.2	11	5684813.56	9.91	0.0001
active_sta	30117998.7	2	15058999.4	26.26	0.0000
c_time	28549728.1	2	14274864	24.89	0.0000
r_work	2393498.3	2	1196749.15	2.09	0.1586
r_ject	33748.091	1	33748.091	0.06	0.8116
op_exper	271049.304	2	135524.652	0.24	0.7924
daily_dmnd	1093875.74	2	546937.871	0.95	0.4075
Residual	8602348.01	15	573489.867		
Total	71135297.2	26	2735972.97		

%Working

Number of obs = 27 R-squared = 0.9253
Root MSE = 12.795 Adj R-squared = 0.8704

Source	Partial SS	df	MS	F	Prob > F
Model	30397.4231	11	2763.4021	16.88	0.0000
active_sta	11908.2553	2	5954.12764	36.37	0.0000
c_time	17856.1138	2	8928.05691	54.53	0.0000
r_work	499.92617	2	249.963085	1.53	0.2491
r_ject	.266175258	1	.266175258	0.00	0.9684
op_exper	7.36165702	2	3.68082851	0.02	0.9778
daily_dmnd	122.063648	2	61.0318238	0.37	0.6950
Residual	2455.69487	15	163.712991		
Total	32853.1179	26	1263.58146		

%Waiting

Number of obs =	27		R-squared =	0.9253
Root MSE =	12.793		Adj R-squared =	0.8705

Source	Partial SS	df	MS	F	Prob > F
Model	30394.8136	11	2763.16488	16.88	0.0000
active_sta	11907.7861	2	5953.89306	36.38	0.0000
c_time	17853.621	2	8926.81052	54.54	0.0000
r_work	500.212537	2	250.106268	1.53	0.2489
r_ject	.262061427	1	.262061427	0.00	0.9686
op_exper	7.39474893	2	3.69737446	0.02	0.9777
daily_dmnd	122.073602	2	61.0368011	0.37	0.6949
Residual	2454.90674	15	163.660449		
Total	32849.7204	26	1263.45078		

WIP

Number of obs =	27		R-squared =	0.8159
Root MSE =	902.083		Adj R-squared =	0.6809

Source	Partial SS	df	MS	F	Prob > F
Model	54097607.5	11	4917964.32	6.04	0.0009
active_sta	31277005.4	2	15638502.7	19.22	0.0001
c_time	12095010.3	2	6047505.15	7.43	0.0057
r_work	9794913.85	2	4897456.93	6.02	0.0121
r_ject	59715.7989	1	59715.7989	0.07	0.7902
op_exper	226322.345	2	113161.173	0.14	0.8713
daily_dmnd	629191.028	2	314595.514	0.39	0.6859
Residual	12206303.6	15	813753.576		
Total	66303911.2	26	2550150.43		

Appendix A 12- Terminal 3 Departure Layout


TO DEPARTURE GATES
First & Business Class check-in
Economy Class check-in
Immigration
Duty Free
First & Business Class Lounge entrance
Services
1 Coach transfer departures
2 First & Business Class check-in
3 Economy Class check-in
4 Check-in office
5 Reservation, Ticket Sales & Unaccompanied Baggage Desk
6 Oversize Baggage counter
7 Immigration
8 X-ray scan
Terminal 3, Abu Dhabi Airport
PREMIUM DROP-OFF
ECONOMY DROP-OFF
TERMINAL 3
TERMINAL 1
ARRIVALS
To Dubai
CARPARK
To Abu Dhabi
From Dubai & Abu Dhabi